BELL AEROSYSTEMS COMPANY

EXPERIMENTAL AUXILIARY ROCKET ENGINE

CONTRACT NAS 7-305

FINAL REPORT

PART II

REPORT NO. 8374-933004

1-5-66

FOREWORD

Part I of this report includes the following:

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TABLES

VI. TECHNICAL DISCUSSION - TASK II

A. FABRICATION OF THE PROTOTYPE ENGINE ASSEMBLIES

1. Design Completion and Procurement

The drawings for the two prototype engines were released for fabrication by June 1, 1965. Procurement orders for all the materials, including the Moog bipropellant valve, were placed by June 4, 1965.

2. Fabrication Schedule and Injector Check Out Firings

Except for fabrication of the two injector blanks in June 1965, the fabrication effort commenced during the first week of July 1965.

A schedule showing the fabrication progress from this date is given in Figure VI-1, with only a limited amount of effort being expended during the first two weeks of July due to the Bell vacation shutdown.

During the fabrication of both orifice plates difficulty was encountered in obtaining proper impingement characteristics, based on water flow inspection, and required rework of each orifice plate.

The first of two prototype injector assemblies (S/N 2) was prepared for checkout fire tests in a columbium test chamber. This test chamber had been used for previous injector evaluation test series and had developed small cracks in the uncoated flange. During the installation of the prototype injector S/N 2 further cracking resulted, causing leakage past the gasket sealing surfaces.

An attempt to repair the columbium test chamber was made, but without success. It was therefore necessary to conduct the checkout fire tests of each prototype injector in a stainless steel test chamber. This resulted in some data compromise since the assembly could not be fire tested to equilibrium temperature conditions.

The stainless steel chamber was instrumented with 22 thermocouples, including six at the throat station and six at the convergent nozzle station. Two chamber pressure transducers were installed on the injector pickup, and one on the chamber pickup.

Prior to installing the prototype injector S/N 2 in the test chamber, the injector was orificed to provide the desirable unbalance between the outboard and inboard fuel orifices. This is accomplished by inserting an orifice in the central fuel tube at the injector-propellant valve interface. This orifice technique is the same as used on the initial unbalanced injector TU-6A. An 0.0512-inch diameter orifice was installed in S/N 2 injector and the injector was reidentified as S/N 2A.

The injector was then subjected to three fire tests of 5-second, 8-second, and 10-second duration. The performance was approximately two percent lower than desired, and a slight erosion streak was noted in the barrel section of the test chamber. Slight misimpingement of two fans in the erosion area were indicated during water flow inspection. Two fuel orifices were reworked slightly to improve the impingement of the streams and the intersection of the fans.

To obtain reasonable correlation of heating rates and performance, the original unbalanced injector TU-6A was also fire tested in the stainless steel chamber. The second prototype injector assembly S/N 1A (orificed with an 0.0512-inch diameter orifice) was then tested. The reworked prototype injector S/N 2A was designated S/N 2B and retested, showing approximately one percent lower performance and no streaking characteristics. For these tests and subsequent series, the stainless steel chamber was rotated approximately 90° to relocate the eroded area in respect to the injector elements. Injector S/N 2B was then reorificed with an 0.055 orifice, identified as S/N 2C and fire tested, resulting in an increase in performance of approximately three quarters percent.

The identification of the three unbalanced injectors used in this series is as follows:

S/N	Configuration
TU-6A	Same as previously tested in C_b chamber with 0.0465-inch orifice in center fuel tube.

S/N	Configuration
1-A	Prototype with 0.0512-inch orifice in center fuel tube.
2-A	Prototype with 0.0512-inch orifice in center fuel tube.
2-B	Prototype with 0.0512-inch orifice in center fuel tube and after rework of injector to eliminate streak.
2-C	Prototype with 0.055-inch orifice (after above rework).

During this entire test series difficulty was encountered in obtaining reasonable correlation between the chamber pressure transducers. For this reason an analysis and comparison of the data was made based on one chamber pressure transducer (that revealed good repeatability). A summary of the tests conducted in this checkout series and the performance and chamber temperature data is given in Table VI-1. A comparison of these same performance and temperature data is shown in Table VI-2.

Based on a c* of 5400 ft/sec obtained with TU-6A injector in the columbium chamber during previous test firings, the specific impulse of the prototype injectors S/N 1A and S/N 2C was predicted to be 286 seconds and 285 seconds, respectively. Bell has concluded that the performance of both prototype injectors was below that obtained with the original unbalanced preprototype injector TU-6A due to the difficulties encountered in the initial drilling of the prototype orifice plates. In the process of drilling each columbium orifice plate, broken drills required hand rework of the injector orifice thereby compromising the reproducibility characteristics of these plates. Improved drilling techniques with the refractory materials will definitely result in higher quality of the injector orifices similar to that obtained with the unbalanced, stainless steel injector TU-6A.

Bell will be demonstrating the manufacturability of a high performance refractory metal injector of the same unbalanced configuration, in production quantities, on a contractual Air Force Program.

3. Fabrication Details

The following items describe the general fabrication techniques used to assemble each of the two prototype engine assemblies.

TABLE VI-1

DATA SUMMARY
UNBALANCED INJECTORS IN S.S. CHAMBER
INJECTORS S/N TU-6A, S/N 1 & S/N 2

Run No.	Injector	Run Dur.	Data Pt.	M.R.	P_c Test	Total Flow	c^*_{corr}	Max. Chamber Temperature	Max. Throat Temperature
2269	2A	5	5	1.52	77.6	0.332	5245	950	515
2270	(0.0512 Orifice)	8	5	1.52	78.0	0.330	5300	1030	585
2271		10	5	1.61	79.3	0.338	5270	1020	550
			10	1.61	78.8	0.338	5240	1640	995
2272	TU-6A	5	5	1.59	81.8	0.340	5405	975	570
2273	(0.0465 Orifice)	10	5	1.59	80.9	0.338	5385	1000	590
			10	1.57	80.4	0.340	5365	1580	1020
2274	1A	5	5	1.62	80.3	0.340	5295	1020	600
2275	(0.0512 Orifice)	10	5	1.60	80.3	0.341	5290	1075	660
			10	1.60	79.0	0.341	5250	1720	1140
2276	2B	5	5	1.64	79.0	0.341	5185	920	515
2277	(0.0512 Orifice	5	5	1.58	78.0	0.335	5190	865	490
2278	after reworking)	10	5	1.59	77.6	0.334	5185	855	500
			10	1.59	77.2	0.335	5170	1420	880
2279	2C	5	5	1.58	78.6	0.339	5185	845	485
2280	(0.055 Orifice)	10	5	1.57	78.8	0.339	5200	860	505
			10	1.57	78.6	0.339	5220	1415	855
2281		10	5	1.35	79.6	0.335	5320	875	535
			10	1.34	77.3	0.334	5215	1410	890
2282		10	5	1.75	76.4	0.339	5035	805	495
			10	1.75	76.2	0.340	5050	1340	825

TABLE VI-1 (CONT)

Run No.	Injector	Run Dur.	Data Pt.	M.R.	P_c Test	Total Flow	c^*_{corr}	Max. Chamber Temperature	Max. Throat Temperature
2283	1A	5	5	1.60	81.8	0.343	5310	980	545
2284	(New 0.0512 Orifice)	10	5	1.58	81.9	0.344	5305	995	570
			10	1.58	80.0	0.343	5255	1570	980
2285		10	5	1.37	82.2	0.343	5340	1020	605
			10	1.36	81.0	0.341	5335	1600	1010
2286		10	5	1.79	80.1	0.343	5205	930	590
			10	1.79	79.3	0.343	5205	1575	1010

TABLE VI-2

PERFORMANCE AND TEMPERATURE COMPARISON

COMPARISON OF UNBALANCED INJECTORS IN S. S. CHAMBER

	Maximum Chamber Temp. (°F)	Maximum Throat Temp. (°F)	Average Chamber Temp. (°F)	Average Throat Temp. (°F)	c* Corr.	% c* Variation
TU-6A	1580	1020	1500	870	5365	
2A	1640	995	1445	835	5240	
Δ 2A	+60	-25	-55	-35	-125	-2.5
*TU-6A-VS-1A	1720	1140	1525	915	5250	
Δ 1A	+140	+120	+25	+45	-115	-2.1
TU-6A-VS-2B	1420	880	1390	765	5170	
Δ 2B	-160	-140	-110	-105	-195	-3.5
*TU-6A-VS-2C	1415	855	1380	775	5220	
(MR = 1.6)	-165	-165	-120	-95	-145	-2.7
TU-6A-VS-2C	1410	890	1365	785	5215	
(MR = 1.35)	-170	-130	-135	-85	-150	-2.8

a. Injector Assembly (Figures VI-3 to VI-8)

(1) Orifice Plate - machined from columbium (1% zirconium) bar stock.

(2) Orifice Plate Assembly - the columbium (1% zirconium) inserts and titanium support cage were E.B. welded to the orifice plate.

(3) Injector Assembly - the stainless steel capillary tubes were brazed to the columbium inserts and to the stainless steel valve adapter plate. The adapter plate and the phenolic spacer were bolted to the titanium support cage.

b. Thrust Chamber (Figures VI-9 to VI-12)

(1) Chamber - machined from columbium (291) bar stock.

(2) Nozzle Extension - spun and machined from columbium (1% zirconium) sheet stock.

(3) Thrust Chamber - the chamber and nozzle extension were EB welded, then the entire assembly was coated with a silicide 508-C oxidation resistance coating (Sylcor), internally and externally.

c. Thrust Chamber Assembly (Figure VI-13 and VI-14)

(1) The columbium (1% zirconium) support cone was EB welded to the injector assembly; then the injector assembly was EB welded to the thrust chamber.

d. Engine Assembly (Figures VI-15 through VI-25)

(1) Insulation Shell (alumina bubble container) - the shell was fabricated from columbium (1% zirconium) sheet stock, shaped and TIG welded, then coated with a silicide 508-C coating both internally and externally. This shell was installed over the thrust chamber assembly by heating the shell to approximately 800°F for approximately 15 minutes. The shell was positioned in place by lightly peening at the columbium support cone end at three positions, approximately 120° apart.

(2) Mounting Flange - the titanium mounting flange was EB welded to the columbium support cone.

(3) Internal Thermocouples - three Pl - Pl/Rh thermocouples were inserted through the columbium shell into the alumina bubble cavity and positioned 1/4 inch from the external surface of the thrust chamber at the throat and convergent nozzle station. These thermocouples were not attached directly to the thrust chamber surface due to the concern for chemical incompatibility and the possibility of any external oxidation of the substrate causing

eventual failure of the chamber. The thermocouples were held rigidly in position with the ceramic beads that separate the two thermocouple wires. Five additional Pl-Pl/Rh thermocouples were resistance welded to the external surface of the columbium shell.

(4) Alumina Bubble Insulation - this insulation material was purchased from Carborundum Co. and sifted to a screen size between No. 10 and No. 16 mesh. The cavity between the thrust chamber assembly and the columbium shell was filled with alumina bubbles through the fill port on the support cone. The port was sealed with a columbium (1% zirconium) plug provided with small vent holes. During the filling of the cavity the assembly was tapped gently to assure complete filling.

(5) Dyna-Quartz Insulation - this insulation material was purchased from Johns Manville Co. and was shaped to size. The insulation was grooved as necessary to provide clearance for the eight thermocouples along the columbium shell. The four pieces of insulation were positioned on the assembly and hand fitted to assure tight joints. This package was then wrapped with teflon tape at three locations to hold the pieces in position until the fiberglass wrap was installed.

(6) Fiberglass Wrap - the entire package was then wrapped with 2 to 3 plies of WBC 3205-181-935 resin impregnated fiberglass supplied by Western Backing Corporation. The fiberglass was then wrapped with shrink tape and the entire engine was cured in an air oven. This fiberglass outer wrap served as an external protection to the soft Dyna-Quartz and allowed easy handling of the engine.

(7) Stainless Steel Bands - two stainless steel bands and one stainless steel end strap assembly were installed over the fiberglass wrap and were held in position with safety wire. These bands were installed for precautionary purposes should the fiberglass wrap peel or split during the demonstration testing.

(8) Bipropellant Valve - this Model 52 x 125 bipropellant valve was purchased from Moog Inc. and was attached to the injector adapter plate with six bolts and safety wired. Servotronics Co. metal seals, teflon coated, were used at the interface between the propellant valve and the injector assembly.

vacation (7-3-65 to 7-18-65)

July 1965

19	20	21	22	23	26	27	28
M	T	W	T	F	M	T	W

Item	Part No.	July 1965
Injector Assembly	(8374-473100) S/N 1	
Injector Assembly	(8374-473100) S/N 2	
Orifice Plate Assembly	(473101) S/N 1	
Orifice Plate Assembly	(473101) S/N 2	
Orifice Plate	(473102) S/N 1	FAB
Orifice Plate	(473102) S/N 2	FAB D
Injector Blank	(473103) S/N 1 & 2	▽ Both Blanks Available 6-29-65
Inserts (Oxid. & Fuel)	(473104)	
Insulator	(473105)	
Adapter Plate	(473106)	
Valve Support	(473107)	
Tubes (Oxid. & Fuel)	(473108)	
Support Cone Assembly	(473110)	
Thrust Chamber Assembly	(8374-470001) S/N 1	
Thrust Chamber Assembly	(8374-470001) S/N 2	
Chamber Assembly of	(470002) S/N 1	
Chamber Assembly of	(470002) S/N 2	
Chamber	(470003) S/N 1	Procure Mat
Chamber	(470003) S/N 2	Procure Mate
Insulation Jacket	(470004)	▽ 1 & 2 (OSP)
Nozzle	(470005)	▽ 1 & 2 (O
Support Strap	(470006)	▽ 1 & 2
End Strap, Assembly of	(470007)	
Shell	(470008)	Procure Materi
Bolt, Valve (Special)	(470010)	▽ 1 & 2
Flange, Mounting	(470011)	
Seal Retainer	(470012)	
Ring, Seal Spacer	(470013)	
Plug	(470014)	▽ 1 & 2
"Moog" Propellant Valve (52 x 125)		(OSP) (one only)
Alumina Bubbles		(OSP) ▽ 1 & 2

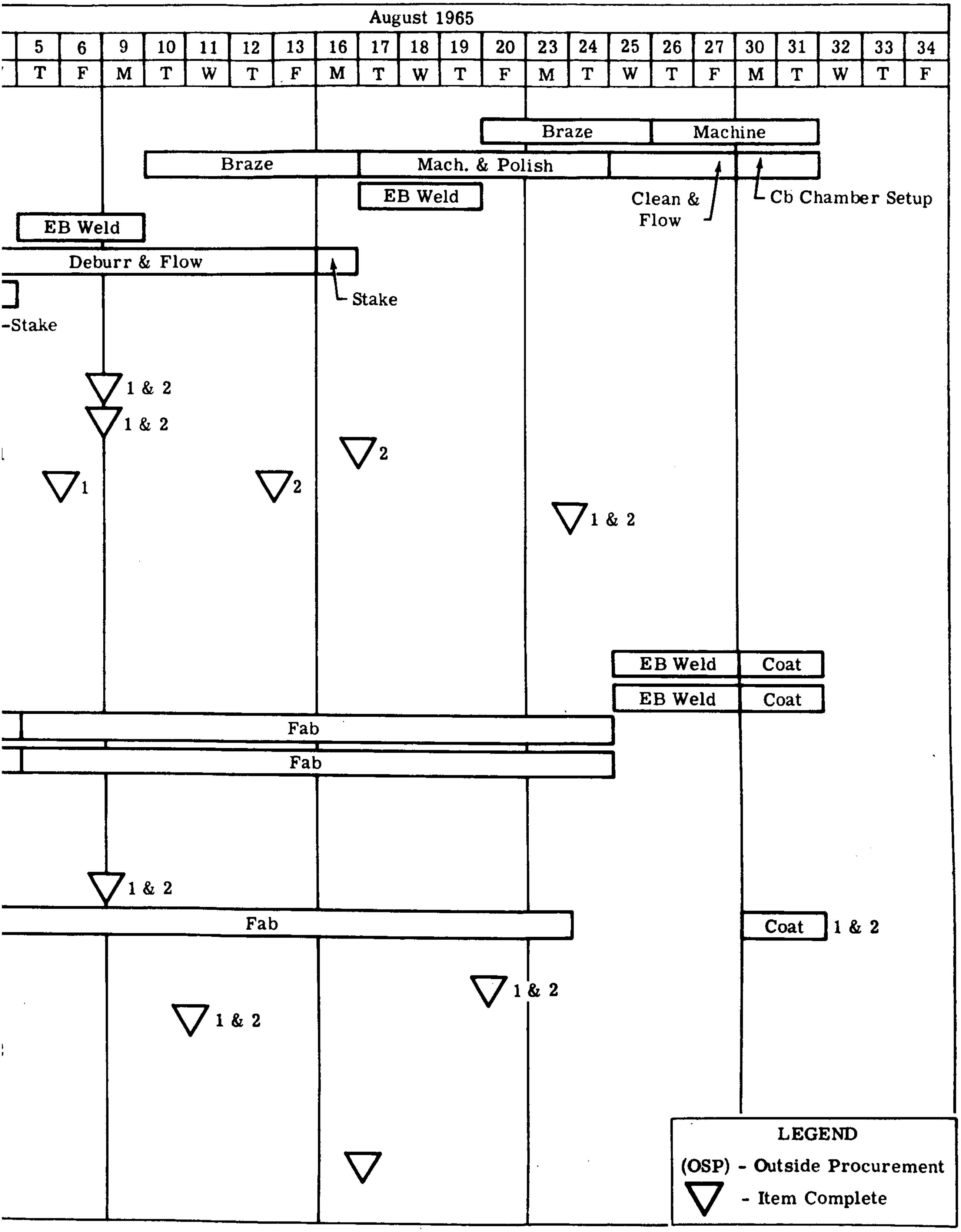


Figure VI-1. Model 8374 (NAS 7-305) Fabrication Schedule - 2 Prototype Engines

		1 W	2 T	3 F	6 M	7 T	8
Injector Assembly	(8374-473100) S/N 1	Polish			H	Clean	
Injector Assembly	(8374-473100) S/N 2	Repair			O	Cb Cl	
Orifice Plate Assembly	(473101) S/N 1				L		
Orifice Plate Assembly	(473101) S/N 2				I		
Orifice Plate	(473102) S/N 1				D		
Orifice Plate	(473102) S/N 2				A		
Injector Blank	(473103) S/N 1&2				Y		
Inserts (Oxid. & Fuel)	(473104)						
Insulator	(473105)						
Adapter Plate	(473106)						
Valve Support	(473107)						
Tubes (Oxid. & Fuel)	(473108)						
Support Cone Assembly	(473110)						
Thrust Chamber Assembly	(8374-470001) S/N 1						
Thrust Chamber Assembly	(8374-470001) S/N 2						
Chamber Assembly of	(470002) S/N 1	Ct	Machine				
Chamber Assembly of	(470002) S/N 2	Ct	Machine				
Chamber	(470003) S/N 1						
Chamber	(470003) S/N 2						
Insulation Jacket	(470004)						
Nozzle	(470005)						
Support Strap	(470006)						
End Strap, Assy of	(470007)						
Shell	(470008)	Coat				1 & 2	
Bolt, Valve (Special)	(470010)						
Flange, Mounting	(470011)						
Seal Retainer	(470012)						
Ring, Seal Spacer	(470013)						
Plug	(470014)						
"Moog" Propellant Valve	(52x125)						
Alumina Bubbles							

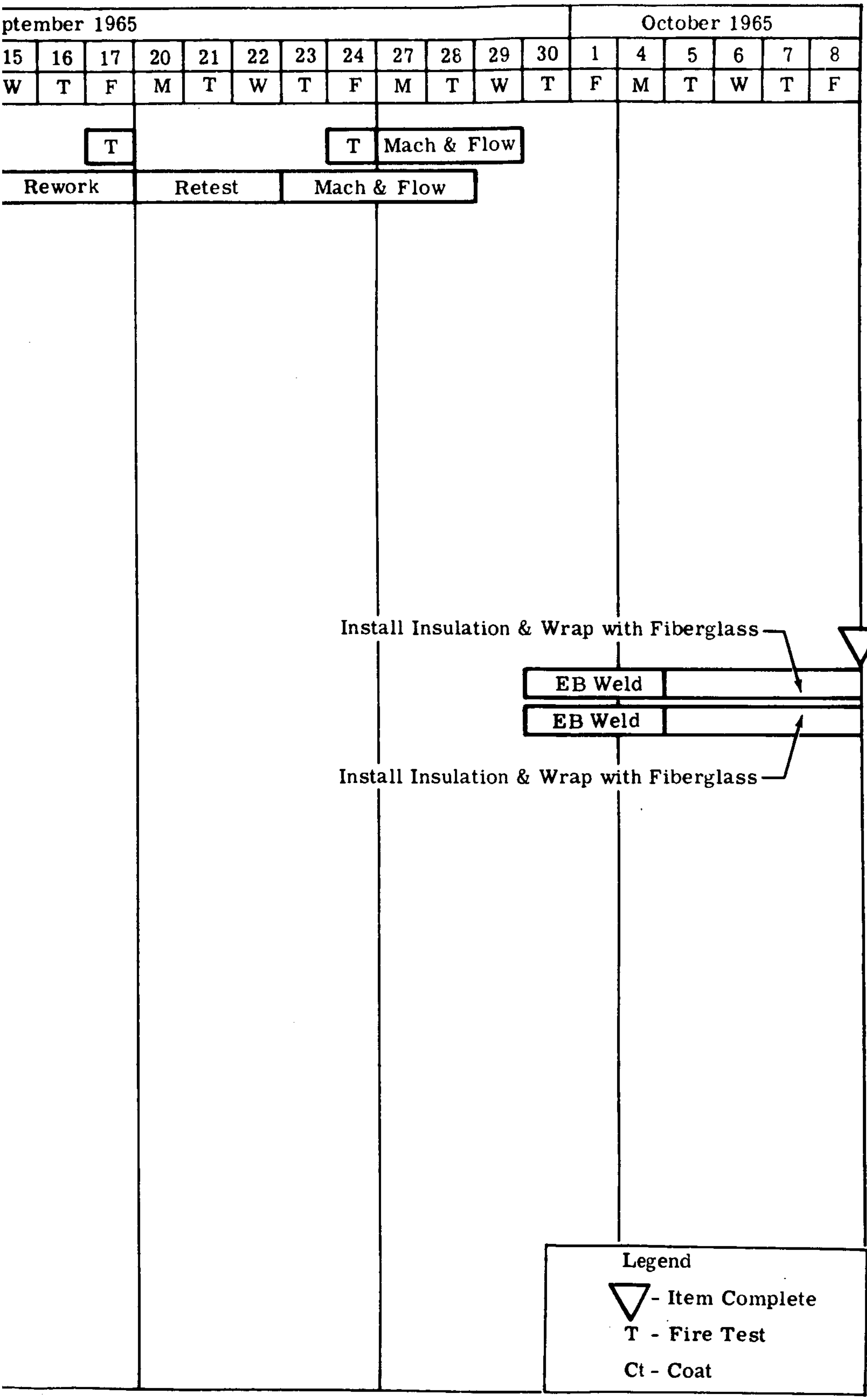


Figure VI-2. Model 8374 (NAS 7-305) Fabrication Schedule - 2 Prototype Engines

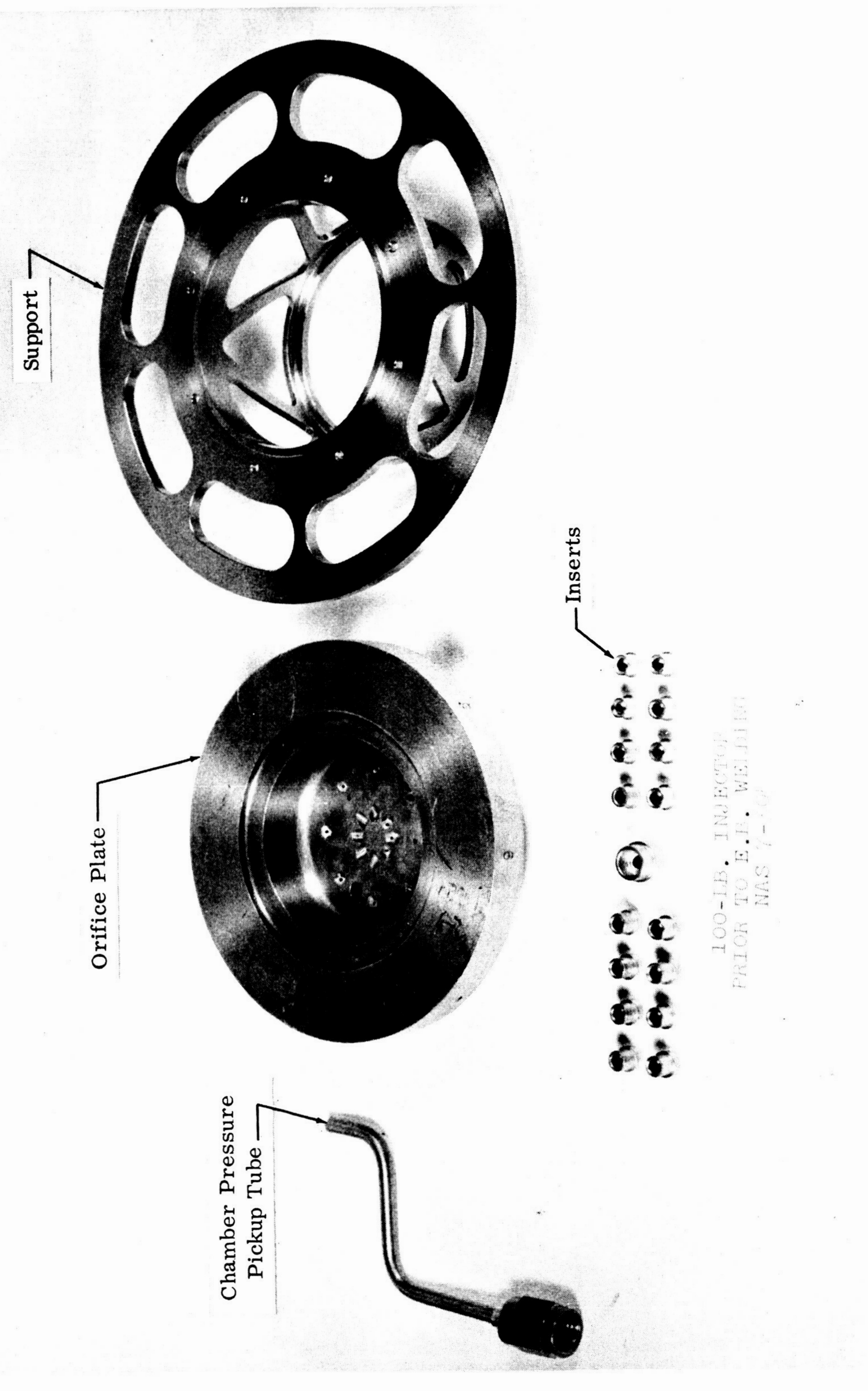


Figure VI-3. 100-lb Injector Prior to Electron Beam Welding

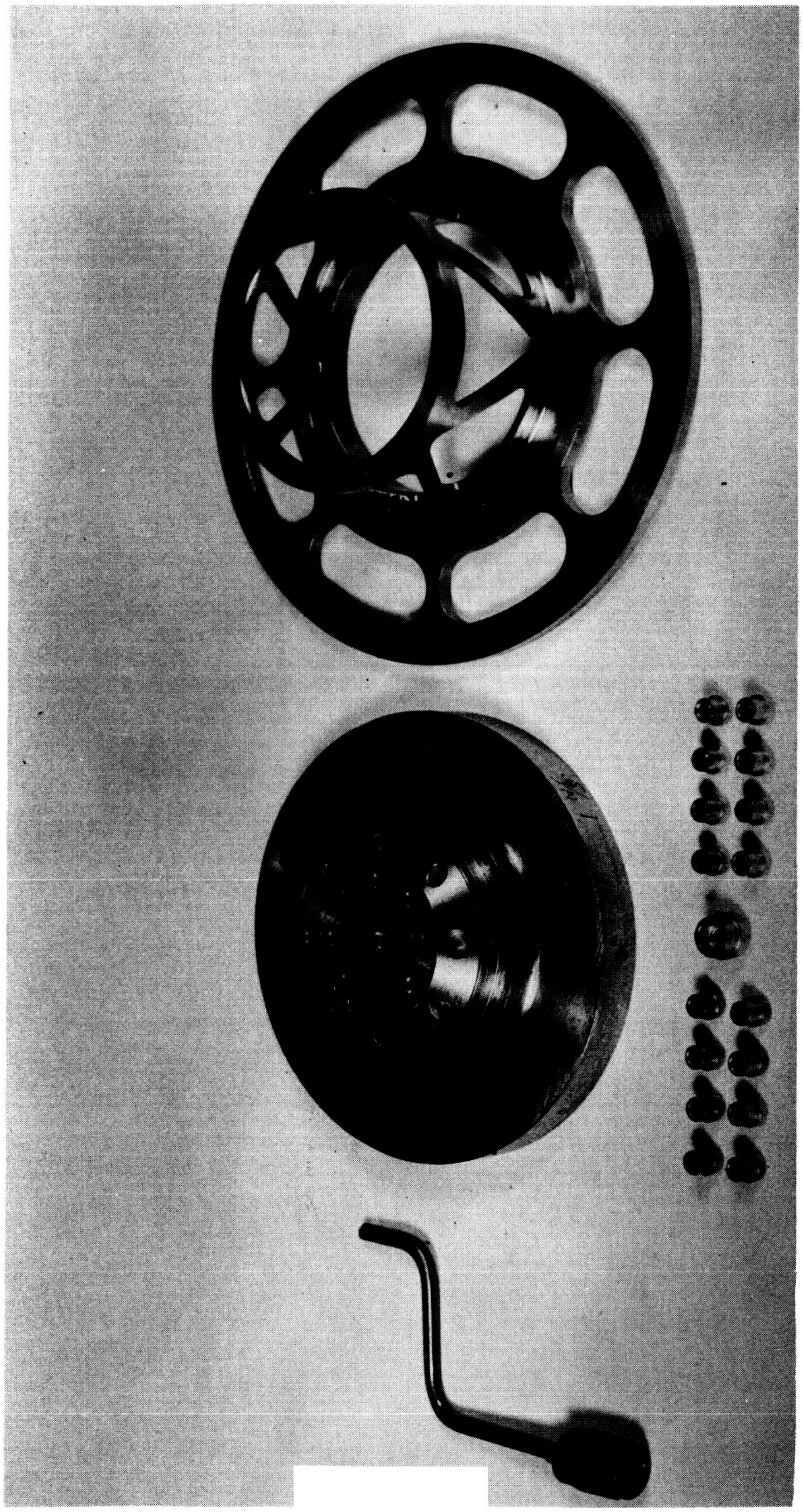


Figure VI-4. 100-lb Injector Prior to Electron Beam Welding

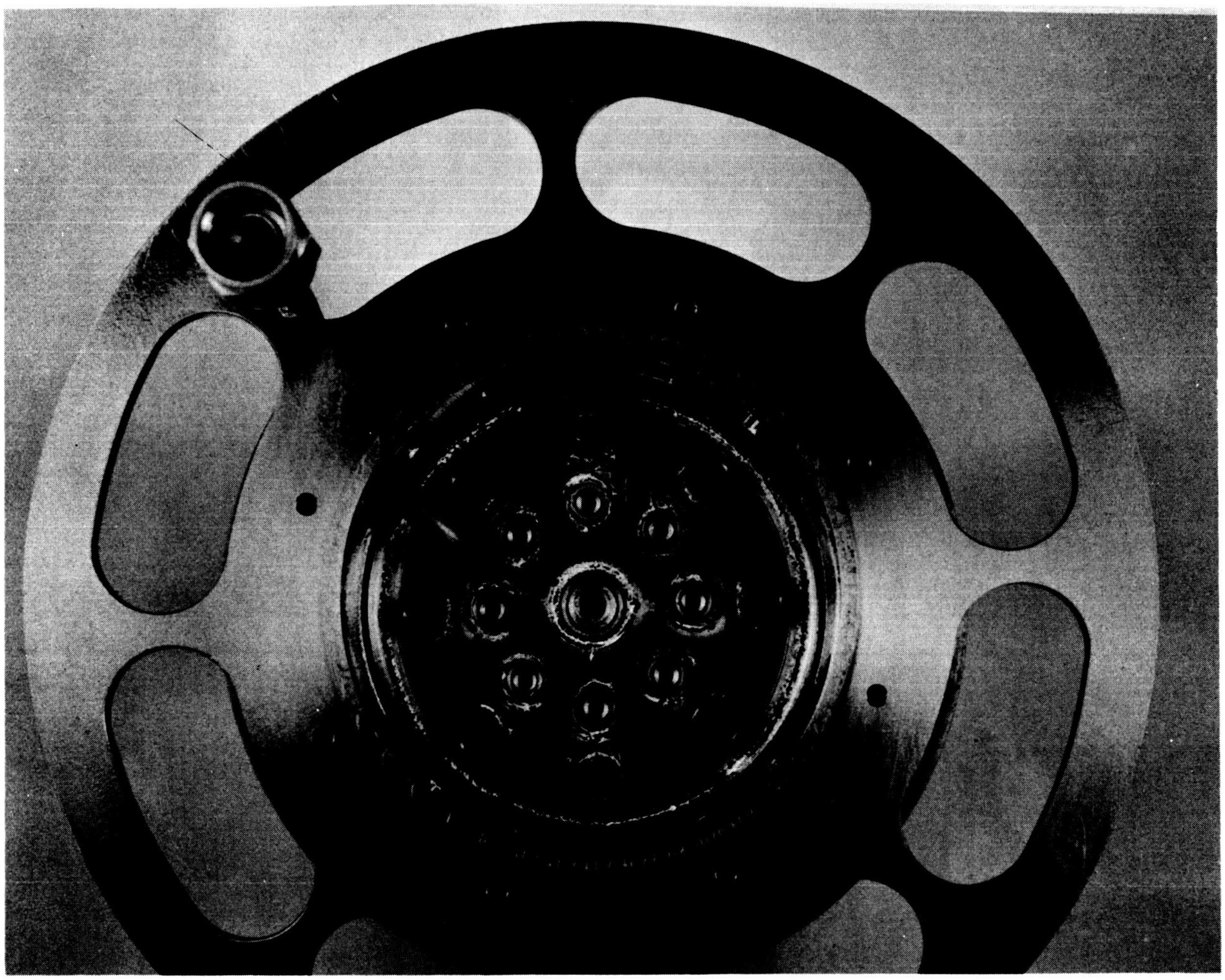


Figure VI-5. 100-lb Injector After Electron Beam Welding

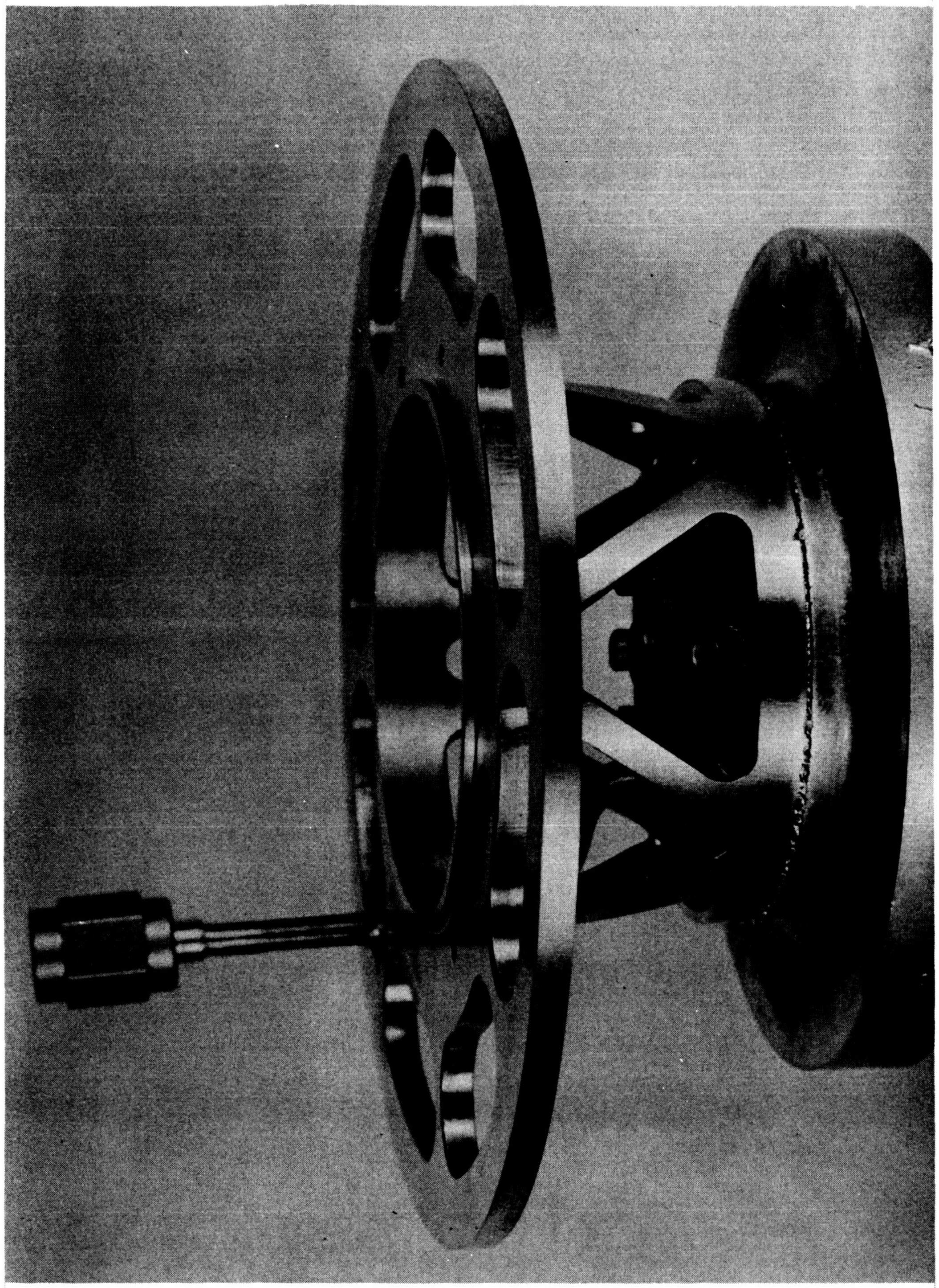


Figure VI-6. 100-lb Injector After Electron Beam Welding

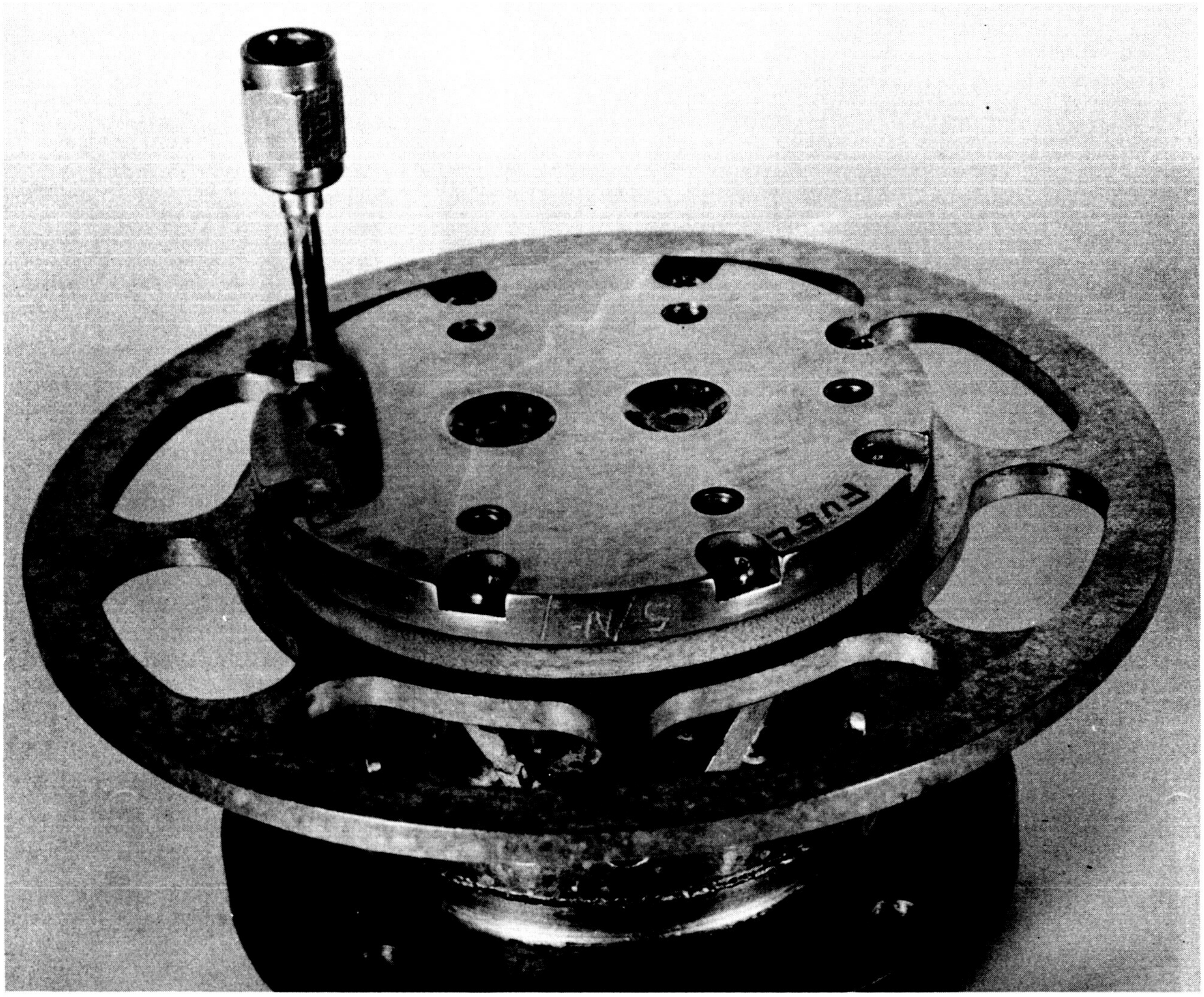


Figure VI-7. 100-lb Injector Assembly After Brazing

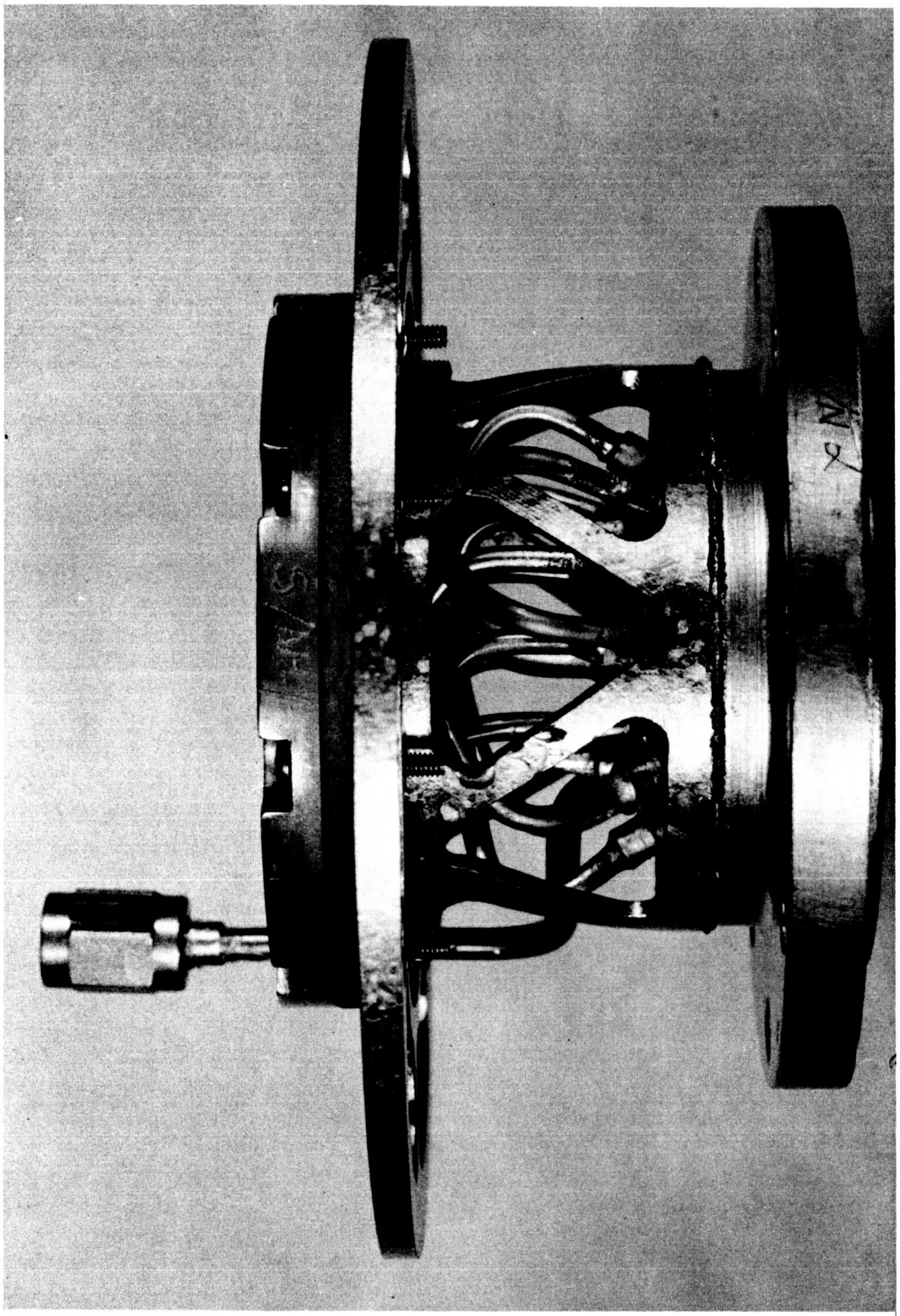


Figure VI-8. 100-lb Injector Assembly After Brazing

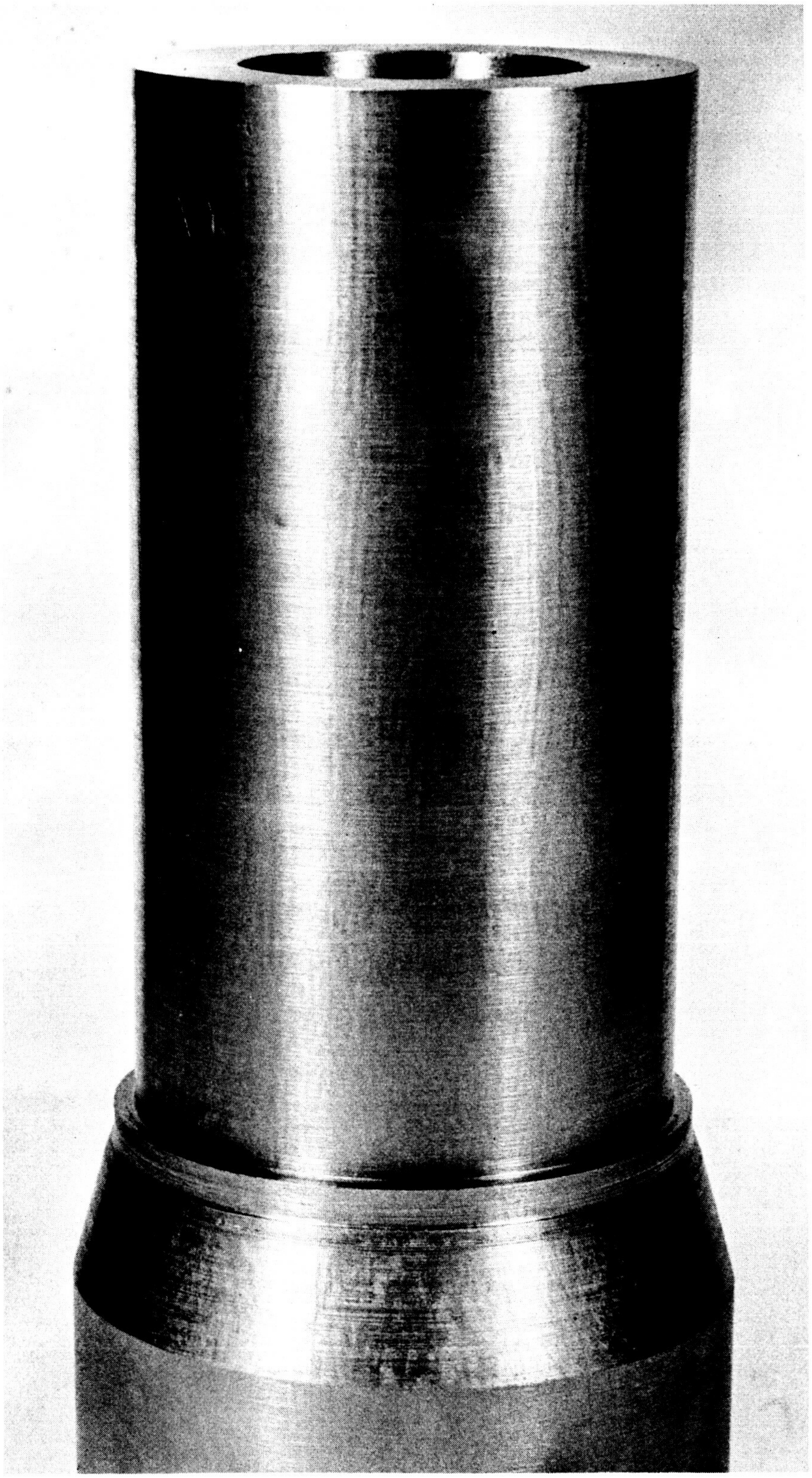


Figure VI-9. Semi-Machined 100-lb Columbium Chamber (Bar Stock)

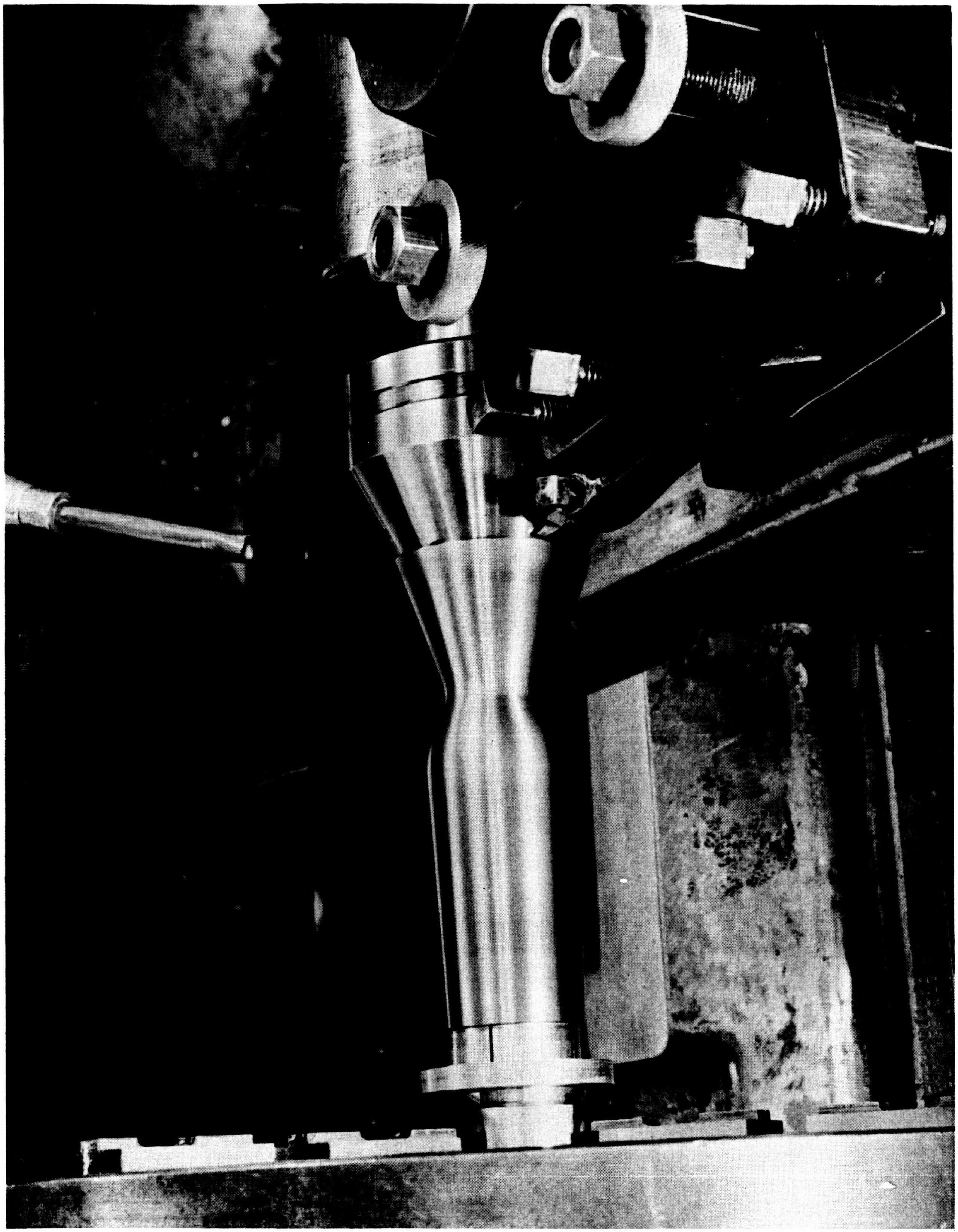


Figure VI-10. Fabrication of Chamber

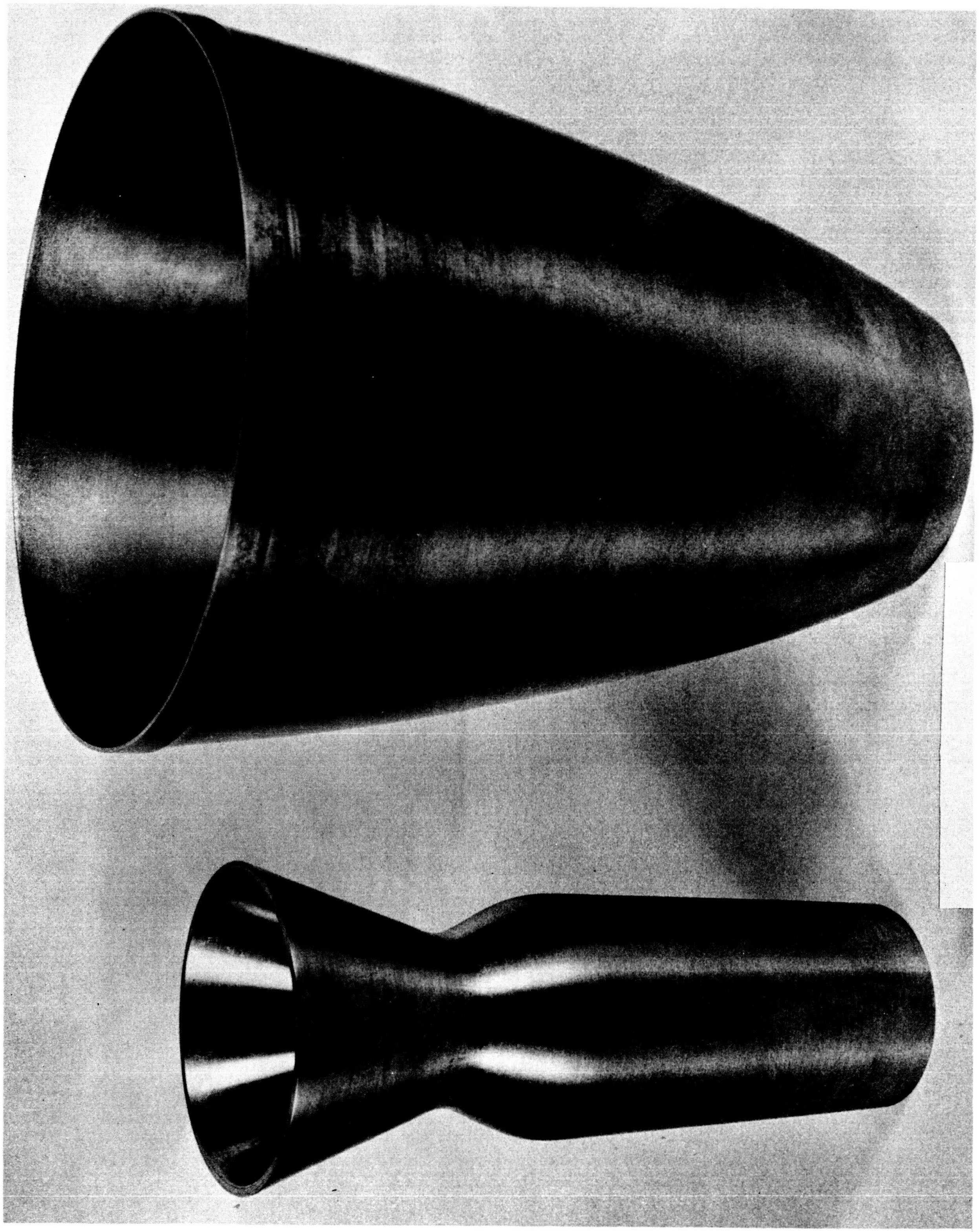


Figure VI-11. Chamber and Nozzle Extension for 100-lb Columbium Engine Prior to Electron Beam Welding

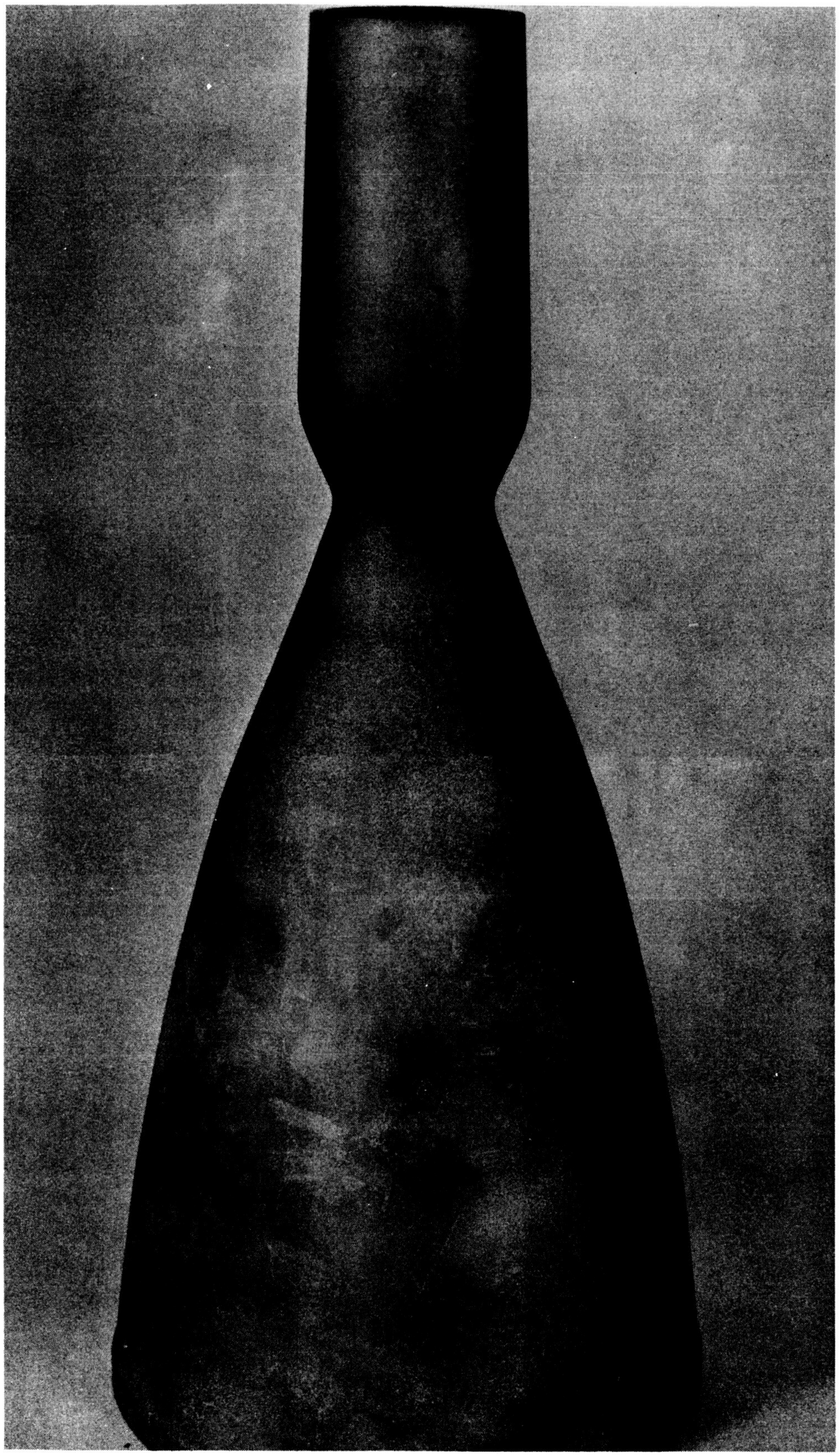


Figure VI-12. Chamber and Nozzle Extension for 100-lb Columbium Engine After Coating

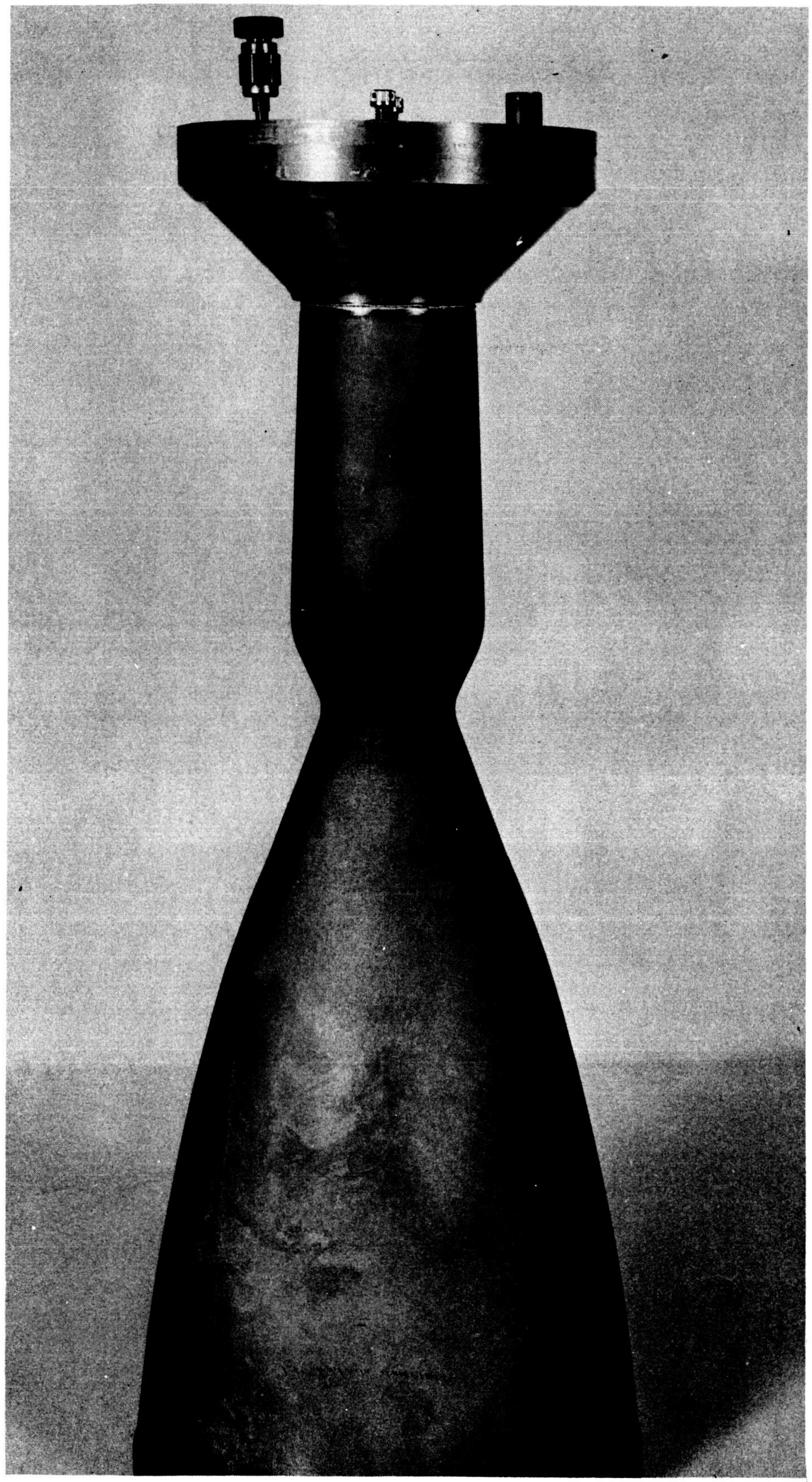


Figure VI-13. 100-lb Thrust Chamber Assembly After Welding Injector and Support to Chamber

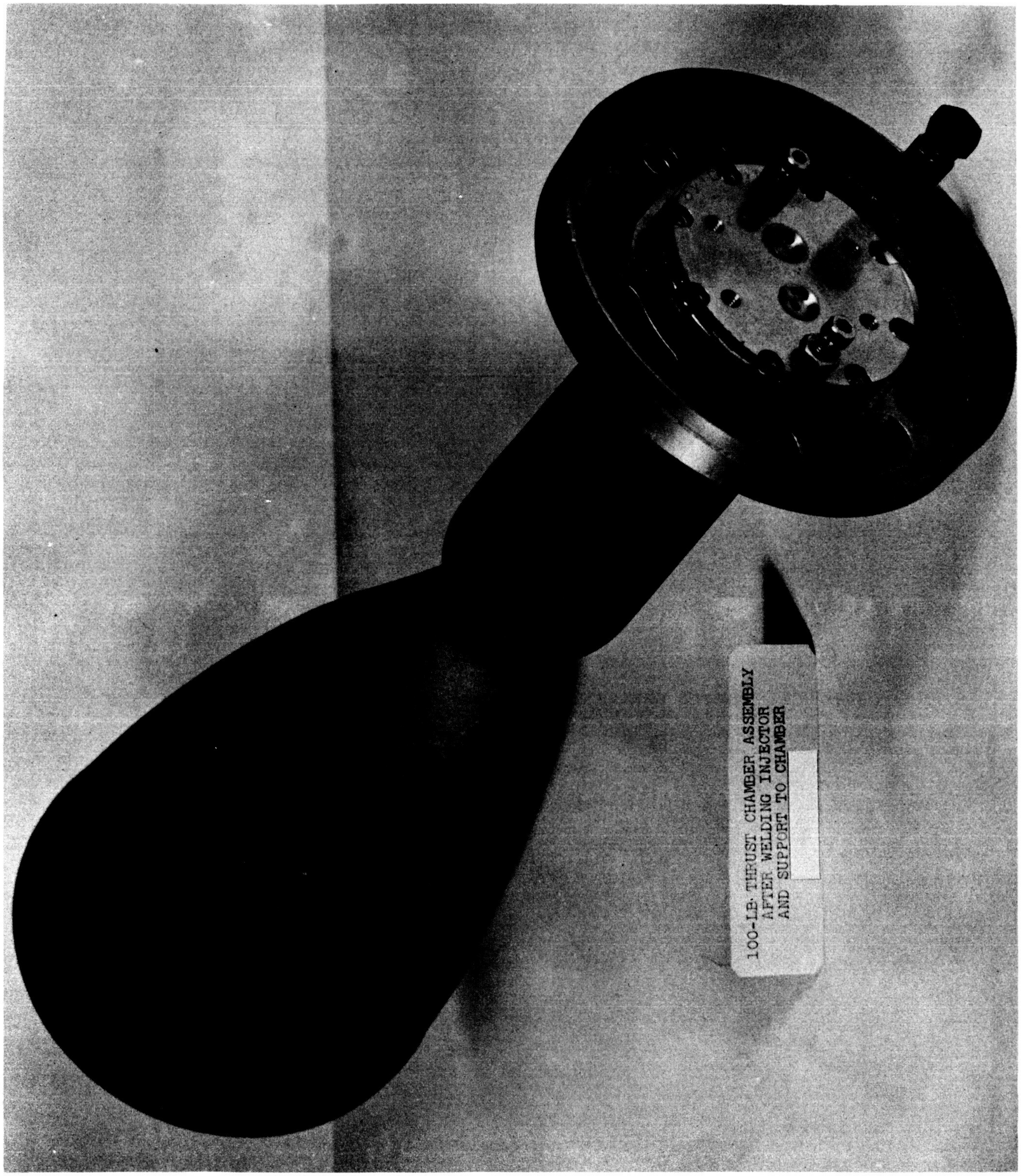


Figure VI-14. 100-lb Thrust Chamber Assembly After Welding Injector and Support to Chamber

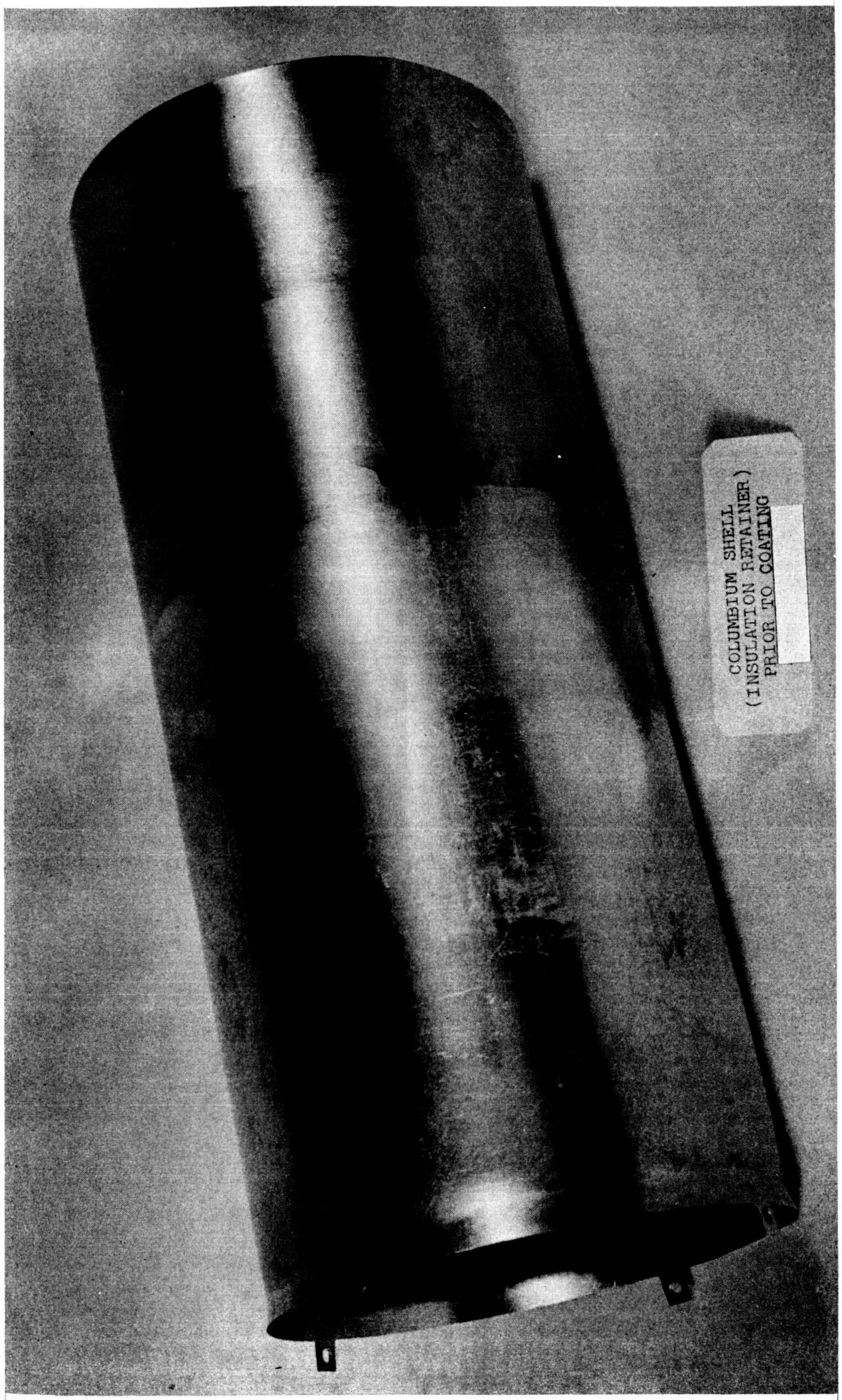


Figure VI-15. Columbium Shell (Insulation Retainer) Prior to Coating

Figure VI-16. Columbium Shell (Insulation Retainer) After Coating

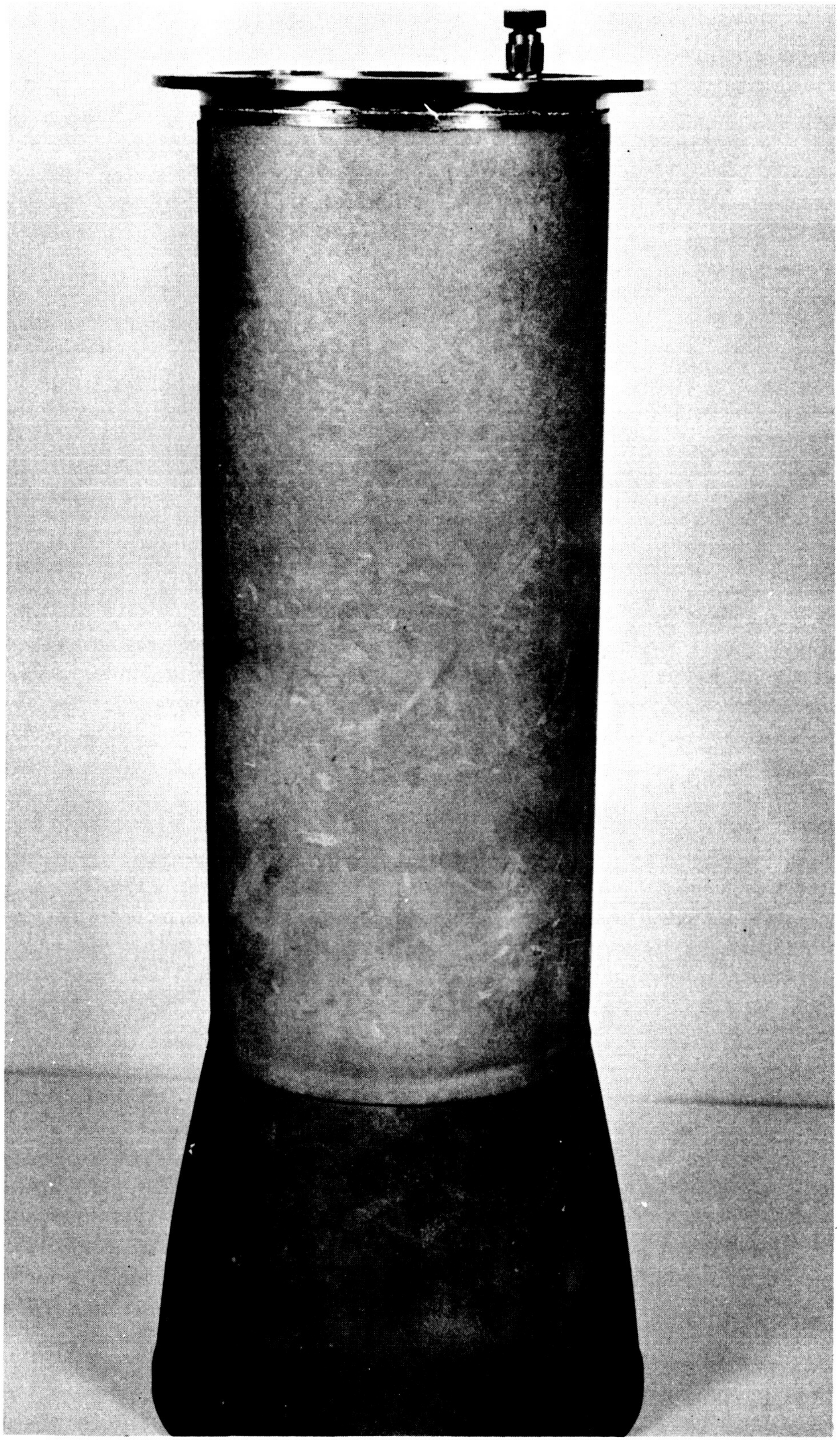


Figure VI-17. 100-lb Thrust Chamber Assembly Before Installing Insulation

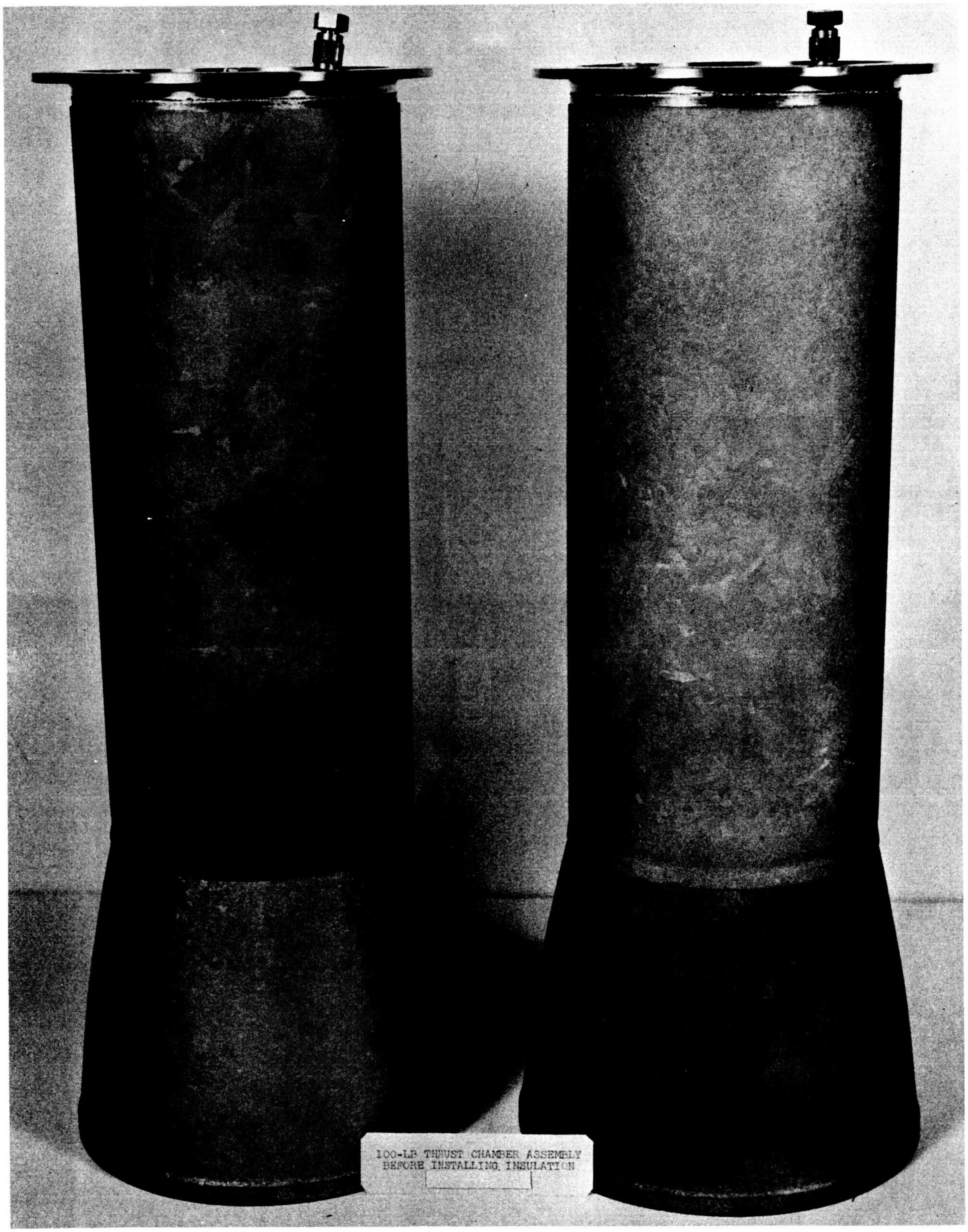


Figure VI-18. 100-lb Thrust Chamber Assembly Before Installing Insulation

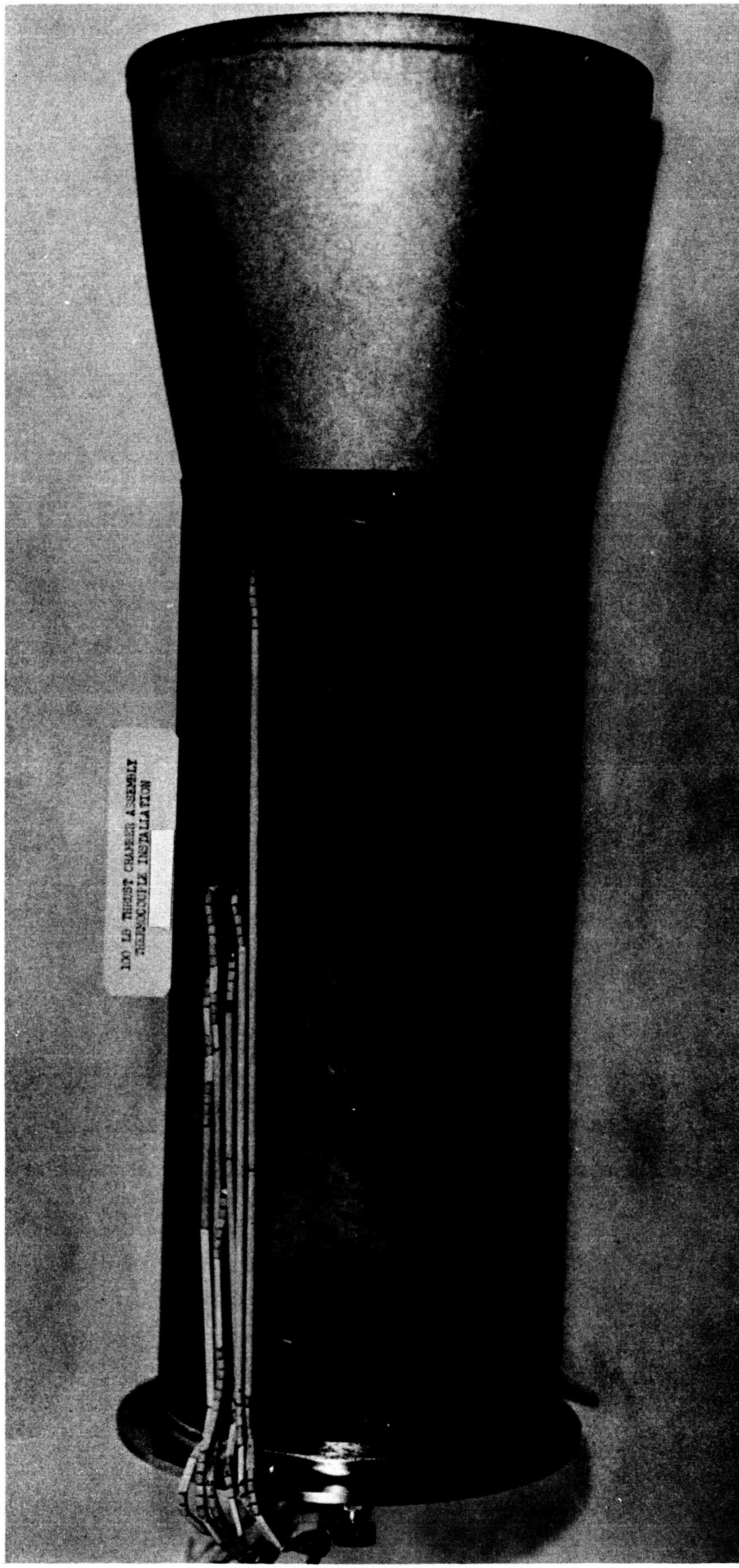


Figure VI-19. 100-lb Thrust Chamber Assembly Thermocouple Installation

Figure VI-20. Dyna-Quartz Insulation

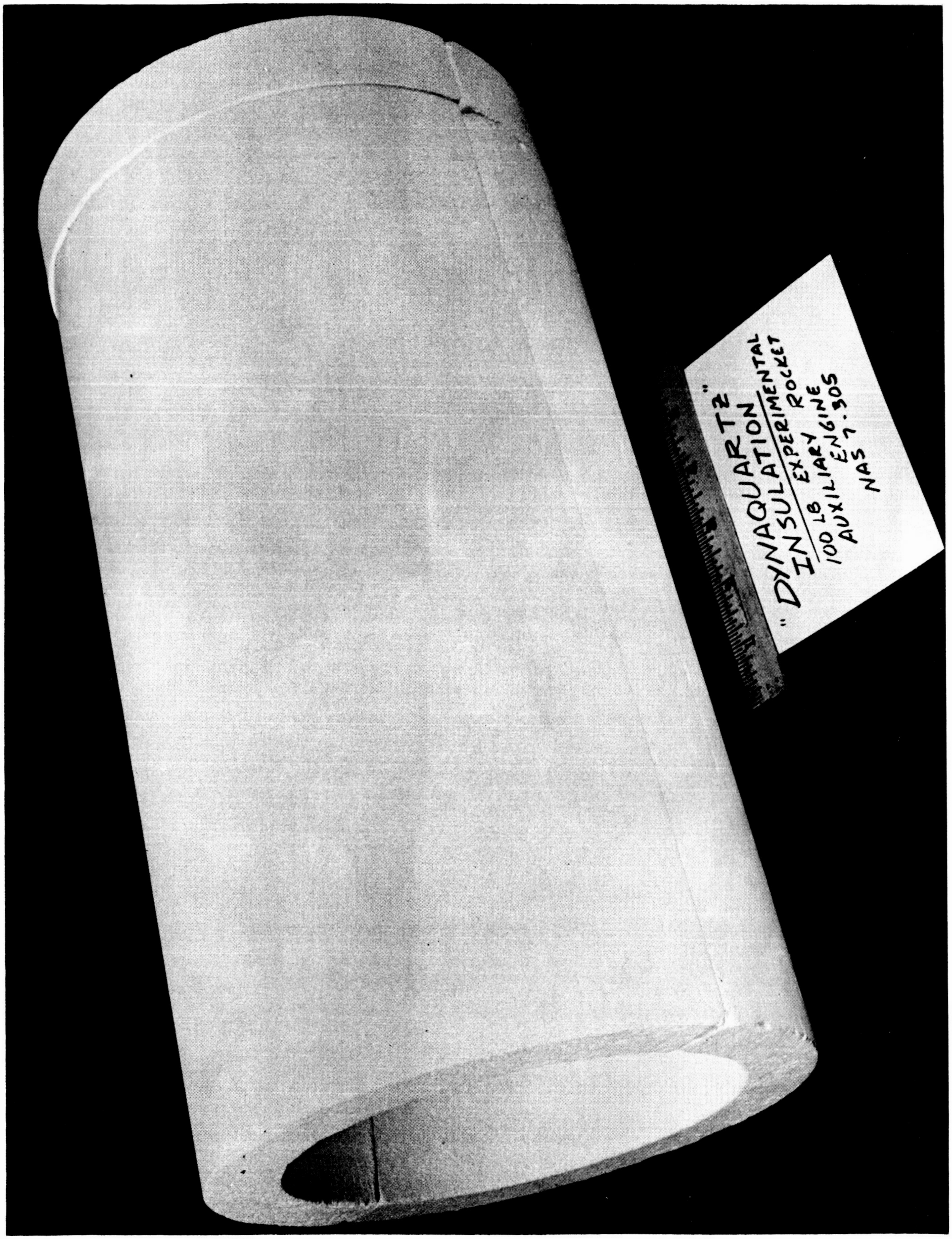


Figure VI-21. Dyna-Quartz Insulation

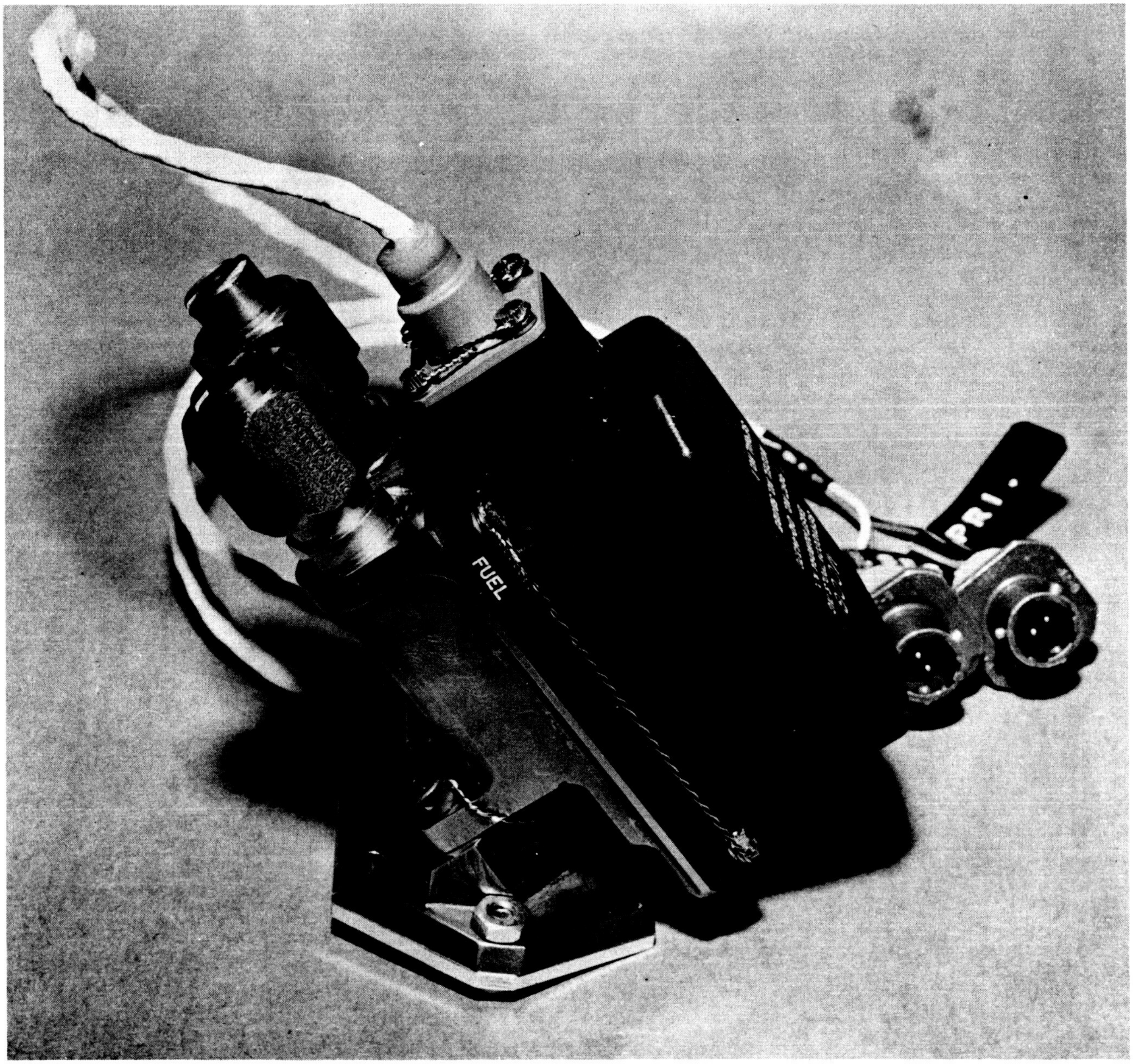


Figure VI-22. Moog Bipropellant Valve

Figure VI-23. 100-lb Thrust Chamber Assembly After Curing Fiber Glass Outer Wrap

Figure VI-24. 8374-470001 100-lb Engine Assembly

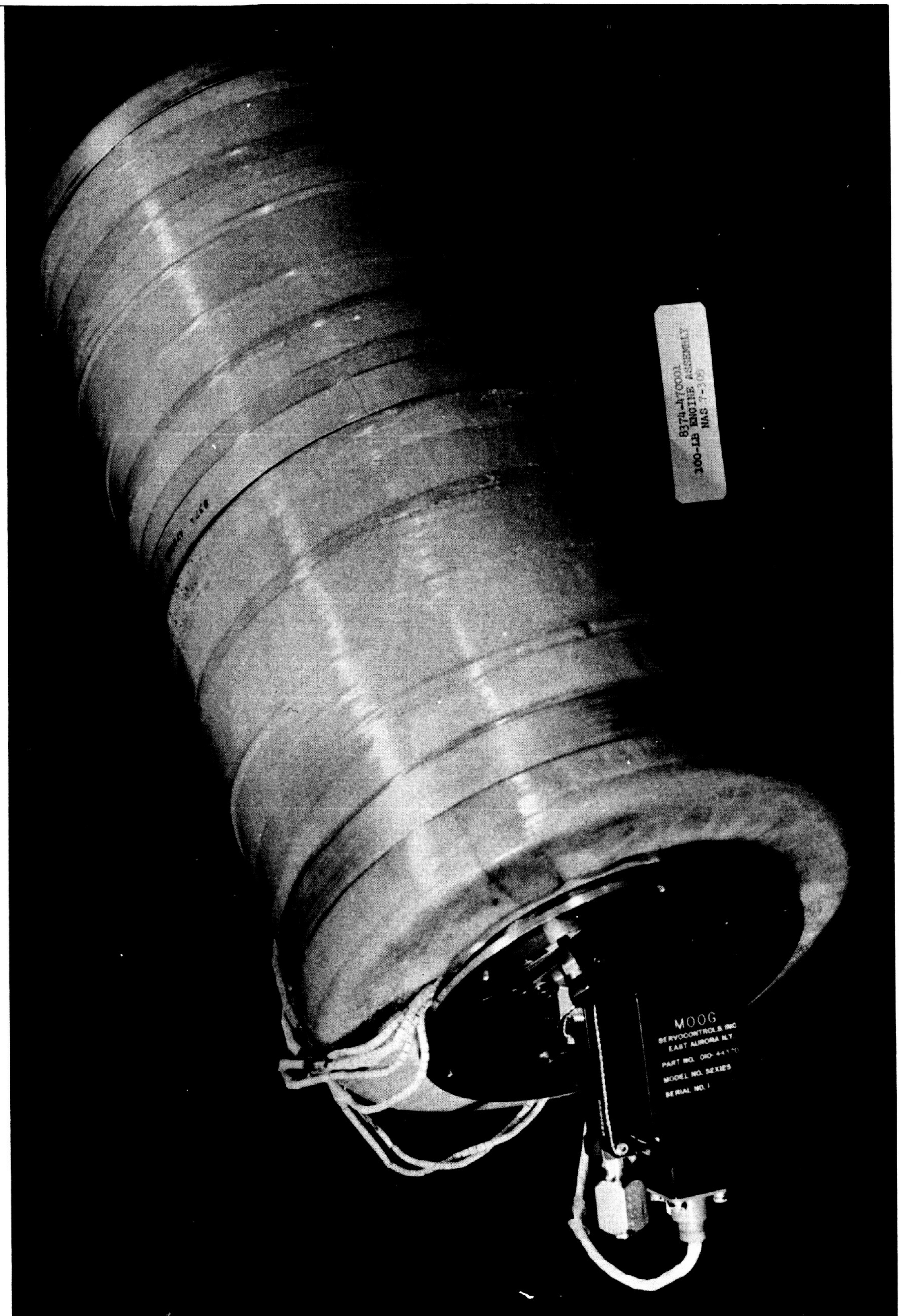


Figure VI-25. 8374-470001 100-lb Engine Assembly

B. DEMONSTRATION TESTING

1. Prototype Engine Assembly S/N 2

a. Thermocouple Attachment

Additional thermocouples were attached to the engine assembly as shown in Figure VI-26 resulting in a total of 38 temperature measurements on the engine. The two injector temperatures (T-1 & T-2) were measured using Cr/Al probes clamped against the back face of the injector. All the remaining thermocouples on the injector assembly and the propellant valve body (excluding cover) were resistance welded. All the thermocouples on the fiberglass, stainless steel end strap assembly and the propellant valve cover were attached with Armstrong A-6 cement (Figures VI-27 and VI-28).

Two thermocouples were attached to the test stand, one positioned 1-1/2 inches below the chamber mounting flange, the other positioned on the bottom stand "stringer" and six inches from the mounting flange.

b. Altitude Test Facility

The demonstration testing was conducted in the altitude test cell 2E-S at the Bell Test Center facility, shown in Figures VI-29 and VI-30. The test cell consists of a 9 foot diameter chamber, 22 feet in length with two steam ejector systems. The large steam system has the capability of maintaining 100,000 feet simulated altitude for 6 minutes, at 400 pound thrust or less. The small steam system can maintain 100,000 feet simulated altitude for a minimum of 48 hours at 20 pounds thrust.

The test stand was modified to provide thrust measurement capability at the 100 pound level. A description of the flexure type thrust stand, calibration fixture and engine mount are shown in Figures VI-31 and VI-32, respectively.

An aspirator duct was used to provide the capability of maintaining 100,000 feet altitude for one hour while fire testing the 100 pound thrust engine. This water cooled duct was designed to provide approximately 1/8 inch annulus between the engine assembly and the aspirator duct.

A one foot diameter opening in the main bulkhead between the altitude chamber and the ejector system allowed rapid evacuation of the altitude chamber with the aspirator

duct in position. During fire testing of the engine assembly this opening was "closed off" using a remotely controlled "flapper valve".

Details of the aspirator duct and the overall installation of the engine in the altitude facility are given in Figures VI-33 and VI-34, respectively.

c. Instrumentation

The type of instrumentation equipment used for this series is as follows:

Parameter	Instrument	Model Number
Thrust	Alinco Load Cell	36-200
Chamber Pressure	Taber	217-100A
Fuel and Oxidizer Feed Pressure	Taber	226-500A
Fuel Flow	Cox	8-6
Oxidizer Flow	Cox	8

Chamber pressure was measured at the face of the injector only, propellant feed pressures and feed temperatures were measured approximately one inch and three inches upstream of the bipropellant valve, respectively. The propellant flowmeters were located approximately 10 feet upstream of the bipropellant valve with propellant temperatures measured between the two flowmeters in each line. A cavitating venturi was installed in each propellant line approximately two feet upstream of the bipropellant valve to assure mixture ratio and total flow control through the long duration test. A schematic of the typical test cell setup is given in Figure VI-35.

d. Test Series - Prototype Engine S/N 2

Six tests were conducted on prototype engine S/N 2 to demonstrate the feasibility of the adiabatic wall design concept for continuous operation for a scheduled one hour period. The installation of the engine assembly is shown in Figures VI-36 and VI-37.

(1) Check Out Tests (Run Nos. 2E-S 1684-1687)

The first four tests were performed as checkout runs and evaluation of the thrust test stand and the aspirator duct. These tests were of 6, 31, 16, and 5 second

duration, respectively. Instrumentation problems were encountered during the first three checkout runs but were corrected prior to the last five second test. During these tests the pressure in the altitude chamber increased slightly, requiring a correction to thrust measurement due to unequal pressure across the engine assembly. A tabulation of the test data for these four tests is given in Table VI-3. .

(2) Long Duration Demonstration Test and Restart (Run Nos. 2E-S 1688, 1689)

This demonstration test was a planned one hour duration test but was prematurely shut down at 29 minutes and 8 seconds due to a gradual decrease in thrust chamber pressure, indicating throat erosion. Difficulty was encountered after approximately two minutes of firing when it was apparent the aspirator duct was not operating properly. The equivalent altitude in the altitude chamber decreased from approximately 120,000 feet at the start of the test to approximately 90,000 feet at two minutes. As the test continued it was apparent that separation was occurring in the nozzle. Visual observation of the engine during the last 20 minutes of the firing revealed damage to the nozzle and to the insulation material became progressively worse.

Since the major purposes of the test were to demonstrate the feasibility of the adiabatic wall design concept and the capability of the coating, the test was continued until thrust chamber pressure gave indication of coating damage or throat erosion. It was realized the temperature data obtained would be somewhat compromised due to the unusual exhaust gas flow characteristics across the exterior of the engine assembly. Thrust chamber pressure was very steady for the first 26 minutes of the test at which time a slight pressure decay of approximately 0.5 psi/min.was noted. At 29 minutes the chamber pressure decay had increased to a rate of approximately 5.0 psi/min. at which time shutdown was made.

After shutdown, heat soak back from the chamber to the propellant valve was allowed to take place until each major component had reached a maximum temperature. During this period the temperature data was monitored and recorded at one minute intervals for a total of 20 minutes. At this time a two second duration firing was made to demonstrate the capability of restarting following a maximum heat soak back condition.

TABLE VI

PROTOTYPE ENGINE S/N 2 -
TESTS 1684 TO

Run No. Date	Run Dur. sec	Data Pt. sec.	① w_f lb/sec	w_o lb/sec	① w_T lb/sec	① M.R.	P_{c_T} psia	c ft
1684, 2E-S	6.3	5.8		0.201			78.1	
10-19-65								
1685	31.2	5.0	0.140	0.205	0.345	1.46	78.9	51
10-20-65		15.0	0.140	0.204	0.344	1.46	79.9	51
		30.8	0.140	0.206	0.347	1.47	79.5	51
1686	16.0	6.0	0.136	0.204	0.340	1.51	79.2	52
10-21-65		15.5	9.136	0.205	0.341	1.51	78.9	51
1687	5.8	5.3	0.134	0.210	0.344	1.57	77.6	50
10-21-65								

① Data unreliable due to questionable fuel flow data.

② Data unreliable due to difficulty with thrust measurement - data not listed.

-3

PERFORMANCE DATA
1687

① T /sec	① c* corr ft/sec	FEP psia	OFP psia	FPVIT °F	OPVIT °F	Altitude Chamber Pressure psia	② F_∞	② I_{sp_∞}
		144.1	148.5	64	65	0.074		
.45	5120	148.0	151.6	72	73	0.049		
.75	5190	148.2	149.6	67	70	0.065		
55	5220	148.8	151.3	64	66	0.114		
:33	5235	149.1	151.0	70	71	0.058		
.88	5205	148.7	150.3	66	68	0.060		
)73	5065	149.7	154.7	65	66	0.066		

(3) Performance Data

A tabulation of the performance data for this 29 minute 8 second test and the two second restart is given in Table VI-4. A tabulation of the temperature data for both tests, including heat soak back data is shown in Table VI-5. Figures VI-38 through VI-41 reveal the temperature profile for various sections of the engine assembly.

(4) Post-Run Inspection

After returning to sea level pressure conditions and following a N_2 gas purge of the engine assembly a visual inspection was made of the assembly on the test stand. The following observations were made:

(1) Severe nozzle damage had occurred.

(2) Slight throat erosion was evident at the 12:30 and 6:00 o'clock positions with chamber wall erosion and burnout noted at 12:30 o'clock position. The burnout was about two inches from the injector face and was approximately 1/2 inch wide and 3/16 inch long. The erosion pattern was approximately one inch wide and two and one-half inches long. A black discoloration was observed on the fiberglass wrap directly "over" the burnout and was approximately one inch in diameter.

(3) At least 50% of the alumina bubbles had been aspirated from the chamber.

(4) The fiberglass wrap was partially charred along the entire length of engine between the 3:00 and 9:00 o'clock position.

(5) Residue had accumulated on the mounting flange and on the bipropellant valve, apparently from the combustion products which had "blown back" into the altitude chamber throughout the firing. Figures VI-42 through VI-45 show the condition of the engine assembly on the test stand following this test series.

The assembly was removed from the test stand and disassembled and inspected. The bipropellant valve was removed from the engine and was flushed and dried prior to installing on the second prototype engine S/N 1. The injector assembly was machined from the chamber, inspected under magnification and water flowed.

Run No. Date	Run Dur. sec	Data Pt. sec	w_f lb/sec	w_o lb/sec	w_T lb/sec
1688	29 min	10 sec	0.133	0.210	0.343
	& 8 sec	1 min	0.133	0.211	0.344
		5	0.133	0.210	0.343
		10	0.132	0.210	0.342
		15	0.132	0.208	0.340
		20	0.132	0.207	0.339
		25	0.130	0.207	0.337
		26	0.129	0.208	0.337
		27	0.130	0.208	0.338
		28	0.130	0.208	0.338
		29	0.130	0.208	0.338
	Heat Soak Back				
		1 min			
		5			
		10			
		15			
		19			
1689	2 sec	static			
		1.0 sec	0.128	0.184	0.312
		2.0 sec	0.130	0.191	0.321
	Heat Soak Back				
		1 min			
		5 min			

TABLE VI-4

PROTOTYPE ENGINE S/N 2 - PERFORMANCE DATA
TESTS 1688 AND 1689

M.R.	P_{c_T} psia	c^*_T ft/sec	c^*_{corr} ft/sec	FFP psia	OFP psia
1.58	79.3	5200	5200	147	152
1.59	79.6	5205	5275	148	155
1.58	79.5	5210	5280	147	155
1.58	79.5	5225	5295	147	155
1.57	79.4	5255	5325	146	155
1.57	79.9	5290	5360	146	155
1.59	78.8	5255	5325	142	154
1.61	78.5	5220	5290	142	154
1.61	78.1	5195	5265	141	155
1.60	77.0	5130	5200	140	153
1.61	71.6	4760	-	135	148
1.44	76.6	5501	-	151	181
1.48	75.6	5292	-	150	-

△ Questionable Data

Run No.	FPVIT °F	OPVIT °F	Altitude Chamber Pressure psia	F_∞ lb	I_{sp_∞} sec (Calc)
1688	62	63	0.068	△	287
	58	58	0.070		291
	61	61	2.15		291
	64	64	3.83		292
	69	70	6.2		294
	69	△	9.0		296
	69	△	10.4		294
	70	70	10.6		292
	70	71	10.8		291
	70	71	10.8		287
	70	71	10.9	△	-
	113	112			
	164	167			
	218	211			
	232	234			
	174	231			
1689	170	221	6.7		
	135	175	6.6	△	
	117	138	6.7	△	
	137	160			
	157	165			

TABLE

PROTOTYPE ENGINE S/N 2 -

Tests 1688

Run No.	Run Duration Min.	Data Point Min.	Inj. 1	Inj. 2	P.V. Flange 7	P.V. Fuel 8	P.V. Fuel 9	P.V. Ox 10	P.V. Ox 11	Mtg Flange 14	Mtg Flange 15	* Fiber-Glass 28
1688	29 min & 8 sec	Static	74	75	76	75	73	88	70	74	71	66
		1	934	847	72	64	63	90	62	153	131	65
		5	1006	960	106	79	70	116	65	343	287	98
		10	1068	1021	126	88	74	129	70	462	394	193
		15	1096	1039	150	103	84	140	79	650	549	434
		20	1168	1081	169	110	86	153	80	737	640	502
		25	1155	1070	181	118	91	158	82	803	709	628
		26	1165	1092	180	118	91	158	82	803	715	604
		27	1187	1088	183	119	91	160	84	804	718	590
		28	1202	1097	184	120	91	160	84	807	720	591
		29	1262	1116	183	120	92	160	84	799	735	600
	Heat Soak Back											
		1	1792	1797	341	234	156	258	112	-	962	595
		2	1686	1694	484	339	200	362	145	-	948	556
		3	1582	1585	494	410	221	421	189	-	909	519
		4	1451	1454	544	460	242	482	230	-	852	493
		5	1384	1387	560	482	258	-	252	-	821	482
		10	1043	1040	524	482	313	504	291	727	657	434
		15	844	836	-	-	308	-	289	600	547	398
		19	636	628	422	268	236	290	273	521	476	371
1689	2 sec	Static	617	610	330	227	230	271	256	486	464	362
		1.0 sec	620	611	330	226	230	270	256	486	462	362
		2.0 sec	632	627	330	226	223	269	241	486	463	362
	Heat Soak Back											
		1 min			258	198	193	190	205	606	357	
		5 min			223	202	197	176	199	573	337	

VI-5

TEMPERATURE DATA (°F)

and 1689

Insulation Temp			Columbium Shell Temp					Ring Support		Structural Support		P.V. Cover	
18	19	25	20	21	22	23	24	3	4	5	6	12	13
-	-	74			76	76	77	74	73	72	73	74	74
387	74	74			307	468	376	442	573	208	158	74	74
1671	439	387			1607	1666	1646	708	788	455	413	92	94
2060	1149	1103			2079	2105	2136	824	922	586	514	102	103
2461	1646	1668			2294	2259	2406	888	1020	714	597	124	127
2805	1986	1994			2523	2459	2589	944	1097	800	673	144	145
2948	-	2194			2606	2501	2676	948	1129	856	712	163	162
2811	-	2212			2622	2518	2703	960	1136	856	712	164	163
2775	-	2226			2633	2525	2731	963	1145	858	716	166	164
2790	-	2147			2648	2538	2755	966	1145	867	724	168	165
2800	-	2613			2660	2560	-	1015	1561	899	729	168	164
2051	2370	2213			2475	2444	-	1598	1602	1017	1017	187	188
1750	2068	1993			2251	2251	-	1536	1512	1017	1017	210	218
1560	-	1837			2071	2089	-	1409	1414	1017	1017	235	246
1386	-	1681			1890	1913	-	1275	1286	1017	1017	260	271
1307	-	1606			1803	1827	-	1206	1224	1017	1017	271	280
962	-	1239			1394	1415	-	900	932	805	812	296	298
761	-	1007			1132	1150	-	727	755	655	658	290	291
738	-	886			989	980	-	578	616	551	535	275	272
762	-	870	3185	127	972	956	-	556	598	533	511	270	266
745	1945	929	-	129	972	955	-	558	606	531	509	269	265
768	1859	1104	2872	129	993	960	-	575	642	537	512	269	265

* See Second Sheet for Note

Run No.	Run Duration Min	Data Point Min	Stand 16	Temp 17	Inj. Flange 33	26
1688	29 min	Static	69	68	67	69
	& 8 sec	1	69	68	68	69
		5	98	74	92	115
		10	157	86	176	249
		15	441	116	505	591
		20	546	151	488	591
		25	591	190	524	591
		26	591	197	508	591
		27	591	203	503	591
		28	591	208	509	591
		29	591	212	497	591
	Heat Soak Back					
		1	579	216	474	-
		2	561	217	452	-
		3	545	548	433	-
		4	526	219	416	-
		5	515	220	408	-
		10	447	217	364	524
		15	394	212	324	451
		19	360	206	295	407
1689	2 sec	Static	354	205	291	400
		1.0 sec	354	205	290	400
		2.0 sec	353	205	290	401
	Heat Soak Back					
		1 min				
		2 min				

* Note: Fiberglass temperatures in excess of normal tative of actual temperature since this thermc

NT)

Fiberglass Temp* 30	31	32	34	35	36	37	38
64	63	60	67	65	70	70	63
64	63	61	67	66	70	70	80
109	304	517	100	149	89	88	591
243	504	591	206	366	135	131	591
457	454	591	581	585	280	250	591
580	591	591	468	591	311	334	591
549	591	591	512	591	354	405	591
543	591	591	508	591	358	415	591
566	591	591	508	591	364	426	591
591	591	591	525	591	372	433	591
591	591	531	510	591	378	438	591
-	532		460		396	449	-
-	372		425		409	457	444
582	281		404		421	460	370
548	228		386		432	461	313
525	218	Lost on Run	378	Lost on Run	434	462	281
392	155		323		405	428	188
304	132		277		358	371	158
258	139		247		325	333	250
252	144	370	243	-	320	218	270
251	203	439	243	-	320	218	270
251	461	-	243	-	320	218	328
						313	
						290	

st gas "blow back". Fiberglass temperature T-36 is more represen-
on the top of the chamber - away from the blow back region.

Figures VI-46 through VI-50 reveal various parts of the engine assembly during disassembly and inspection. Additional observations made during this inspection were as follows:

(1) Compatibility between the alumina bubbles and the silicide coated columbium was excellent (both at the chamber-alumina bubble interface and at the columbium shell-alumina bubble interface).

(2) The alumina bubbles had discolored and fused together at the higher temperature regions along the chamber wall but showed no undesirable characteristics (Figure VI-51).

(3) The Dyna-Quartz insulation was compatible with the silicide coated columbium and, except for melting in the region of nozzle separation and chamber burnout, showed no deterioration due to temperature.

(4) The injector appeared in good condition visually and during inspection under 30X magnification revealed all orifices were clear. Slight oxidation scale was noted around each oxidizer orifice and on the inside surface of each oxidizer orifice. The scale was loose and offered no restrictions to any orifice. The injector face was partially covered with a black-gray residue that was loose and soft and appeared to be "debris" that had fallen in the chamber after burnout. Due to post run handling of the engine this loose debris had partially covered the injector face. A water flow was made of the injector assembly to check for impingement and pressure drop characteristics. The impingement check revealed all orifices were flowing freely and the impingement of all streams were similar to that observed during the previous flow conducted prior to welding the injector to the chamber. The two fans that were not intersecting properly originally revealed similar characteristics, resulting in streams directed in the vicinity of the erosion and burnout region at 12:30 o'clock and the erosion at 6:00 o'clock. The fan from element No. 1 was slightly heavy on on one side and was directed toward the erosion pattern at the 6:00 o'clock position on the convergent nozzle. This correlation between the erosion areas and the injector impingement characteristics and the similarity of impingement before and after fire test indicate that gradual oxidation and erosion was probably occurring throughout the long duration test.

The pressure drop of the fuel side of the injector revealed no change, the oxidizer pressure drop had increased 2 psi.

The identification of the injector impingement is shown in Figure VI-52.

(5) The metal, teflon coated seals used at the propellant valve-injector interface showed no visual signs of deterioration.

(6) The propellant valve operated satisfactorily during the post-run flush and revealed no liquid or N_2 gas leakage. Further discussion is made on the propellant valve in a later section.

2. Prototype Engine Assembly S/N 1

a. Thermocouple Attachment

The thermocouple installation for this assembly was the same as previously described for S/N 2 assembly.

b. Altitude Test Facility

The same test cell and test stand were used as previously discussed for S/N 2 assembly. The small eight inch diameter aspirator duct was removed from the test cell.

The cavitating venturis were removed from the propellant feed lines and an orifice was installed at the inlet to the bipropellant valve. Each orifice was sized for approximately 30 psi pressure drop at rated flow to simulate a trim orifice installation desirable for production type assemblies.

c. Instrumentation

All instrumentation equipment was identical to that used for the S/N 2 assembly.

d. Test Series - Prototype Engine S/N 1

A total of 32 tests were conducted on the assembly at a minimum of 100,000 feet simulated altitude to demonstrate the adiabatic design concept during pulse mode and short duration operation.

(1) Checkout Tests (Run Nos. 2E-S 1691-1693)

The first three tests were performed for checkout purposes. These tests were of 5, 15, and 30 seconds duration, respectively. The large capacity steam ejector system was used for each test.

Following the satisfactory initial five second checkout firing, bipropellant valve seat leakage was noted just prior to conducting the second checkout firing. The engine assembly was removed from the test stand, flushed, and the bipropellant valve was removed from the engine assembly. The bipropellant valve was leak tested with N_2 gas and simulated propellants, revealing the following leakage rates:

	Fuel Side		Oxidizer Side	
	N_2 Gas cc/min	Methonal cc/min	N_2 Gas cc/min	Methylene Chloride cc/min
Before Liquid Flush and Cycling (At 300 psig inlet pressure)	900	0.13	330	0.83
After Liquid Flush and Cycling (At 300 psig inlet pressure)	-	8.5	-	3.4

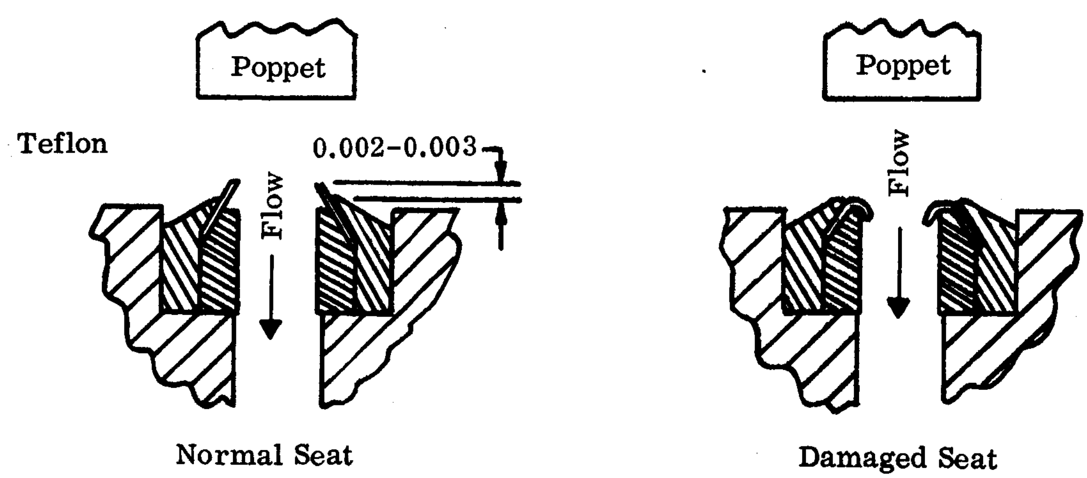
Inspection of the seats revealed the following:

(1) The teflon seats had been rolled over into the valve orifice (see sketch below).

(2) The height of the teflon was even with and in some spots below its metal (SST) retainer.

(3) The teflon material had a very noticeable glazed appearance in contrast to the dull grey appearance of a new seat.

(4) No gouges, nicks, scratches or evidence of harmful contamination was noticed.



The cause of the seat failure has been attributed to the exposure of the valve to excessive temperatures following hot firing. After shutdown of the 30 minute firing test, soakback temperatures between 500°F and 565°F were experienced at the outlet of the

valve in the vicinity of the valve seats. Teflon has a melting point between 545°F and 563°F. It has been reasoned that the teflon was extruded from its retainer due to the high temperatures. The teflon was structurally weakened by the thinning effect of extrusion as well as the high temperature. The subsequent static load of the poppet on the seat as well as the dynamic loads created by cycling the valve caused the teflon to roll over into the orifices. (Cycling was performed on two subsequent hot fire tests and also in post-fire purging and flushing operations). The teflon was so malformed that the poppet was bottomed on the metal seat retainers and only partial contact with the teflon was made, resulting in propellant leakage. The glazed appearance of the teflon further substantiates malforming due to high temperature.

The valve was repaired by replacing both seat assemblies. Leakage tests conducted after the repair showed zero GN_2 leakage in five minutes for both sides of the valve. Operation of the valve was normal and was deemed not otherwise affected by the high temperature experience. The valve was brought back to Bell and subsequently used satisfactorily in steady-state and pulse mode hot firing tests.

The excessive temperature is attributed to the abnormal conditions that existed during the long duration firing on engine S/N 2 when exhaust gas "blow back" heated the engine and test stand to abnormally high temperatures.

The repaired propellant valve was reinstalled on engine S/N 1, the engine assembly was reinstalled in the altitude facility and the checkout tests were repeated with satisfactory results. A tabulation of the test data for the three checkout tests is given in Table VI-6 .

TABLE VI-6

S/N 1 ENGINE DATA

Run No.	Dur sec	Data P_T sec	P_{ct} psia	M.R. O/F	c^*_T ft/sec	c^*_c ft/sec	F_∞ lb	$I_{sp\infty}$ sec	$C_{f\infty}$
1691	5	5	79.5	1.62	5257	5252	101.4	298.5	1.83
1692	5	5	80.4	1.55	5208	5203	104.9	302.6	1.87

(2) Pulse Mode Tests (Run Nos. 2E-S 1694-1704)

The next eleven tests consisted of various types of pulse mode series, including a typical Apollo Command Module Duty Cycle. Following each pulse series the hardware temperatures were monitored during the heat soak period until all temperatures reached a maximum. The small steam ejector system was used for these pulse tests and provided a simulated altitude in excess of 100,000 feet. These tests were as follows:

Run Nos. 1694, 1695 and 1696 were conducted to evaluate two 10% duty cycles and one 1% duty cycle. A large number of pulses were performed on Run No. 1694 in an attempt to approach the quasi-steady state temperature condition for the engine assembly. The remaining two pulse series were made with approximately the same total energy input to the engine as for Run No. 1694. A visual inspection of the assembly was made following Run No. 1695 and showed no indication of erosion. The type of duty cycle operation is shown in Table VI-7.

Run No. 1697 consisted of a five-second steady state performance check run.

Run No. 1698-1702 were conducted to evaluate the capability of the engine to operate during very short electrical "on times" and to determine the type of pulse repeatability. The type of duty cycle operation is also listed in Table VI-7.

Run No. 1703 was a five-second steady state performance check run.

Run No. 1704 subjected the engine assembly to a typical Apollo Command Module Duty Cycle. The duty cycle was performed by controlling the bipropellant valve "fire" sequence and instrumentation recording with a magnetic tape. The conditions of this duty cycle are given in Table VI-8.

A visual inspection was made of the engine assembly following this pulse series and again revealed the chamber to be in excellent condition.

A summary of the performance data for the steady state check firings and the longer duration firings in the Apollo Duty Cycle are given in Table VI-9. The data reveals no degradation in performance following the "more than" 4800 pulses. Temperature data are given in Table VI-10 and Figure VI-53 through VI-58.

TABLE VI-7

DUTY CYCLE DESCRIPTION

Run No. (2 ES)	On Time (sec)	Off Time (sec)	% Duty Cycle	No. of Pulses
1694	0.030	0.270	10	3000
1695	0.100	0.900	10	1000
1696	0.100	9.9	1	150
1698	0.010	60		10
1699	0.020	60		10
1700	0.030	60		10
1701	0.040	60		10
1702	0.010	60		4

Representative oscillograph traces of these tests are shown in Figures VI-59 through VI-65. It must be noted that chamber pressure response is very poor due to the long coupling on the transducer. The thrust trace is representative of actual thrust except during the shutdown transient. This shutdown trace shows oscillations due to the dynamics of this steady state stand.

(3) Mixture Ratio and Chamber Pressure Series (Run Nos. 1705-1714)

These 10 tests were performed to evaluate the effect of mixture ratio and chamber pressure. The high capacity steam ejector system was used for these tests, which consisted of the following: (Engine installed in test cell is shown in Figures VI-66 and VI-67).

Run No.	Duration (second)	P_c (Nominal) (psia)	Mixture Ratio (Nominal)
1705	10	80	1.6
1706	10	80	1.6

TABLE VI-8

TYPICAL APOLLO C/M REACTION CONTROL ENGINE DUTY CYCLE

Time at Start of Pulse Train	No. of Pulses	Total Length of Fire	Individual Pulse Width (secs)
0	1	1.250	1.250
2.2	1	0.050	0.050
15	1	0.250	0.250
18.8	12	0.240	0.020
21	4	0.080	0.020
31	1	2.5	2.500
44	1	1.0	1.000
50	70	1.4	0.020
61	28	0.56	0.020
65	1	0.02	0.020
66	1	0.02	0.020
74	1	1.5	1.500
83	1	1.0	1.000
91	1	0.25	0.250
99	1	0.5	0.500
106	1	0.25	0.250
119	1	2.0	2.000
133	1	1.0	1.000
139	1	0.5	0.500
159	1	1.5	1.500
169	1	1.0	1.000
179	1	0.25	0.250
199	1	0.02	0.020
249	1	0.02	0.020
309	4	0.08	0.020
349	1	15.0	15.000
369	2	0.04	0.020
389	1	0.02	0.020
395	9	0.900	0.100
398	1	0.05	0.050

TABLE VI-8 (CONT)

Time at Start of Pulse Train	No. of Pulses	Total Length of Fire	Individual Pulse Width (secs)
399	1	0.05	0.050
401	1	0.05	0.050
404	1	0.05	0.100
406	16	1.6	0.100
412.6	1	0.05	0.050
413	2	0.10	0.050
415	1	0.05	0.050
418.8	1	0.05	0.050
423,6	1	0.05	0.050
428	1	0.05	0.050
430	1	0.05	0.050
436	1	0.05	0.050
447	1	0.02	0.020
453	1	0.02	0.020
464	1	0.05	0.050
467.6	16	1.6	0.100
476	1	0.05	0.050
483	9	0.9	0.100
487	1	0.05	0.050
489	1	0.05	0.050
489.5	1	0.05	0.050
492	1	0.05	0.050
498.4	1	0.05	0.050
499	1	0.05	0.050
509	1	0.05	0.050
516	1	0.02	0.020
519	1	0.02	0.020
526	1	0.02	0.020
529	1	0.05	0.050
534.2	1	0.05	0.050
538.6	1	0.02	0.020
540	1	0.02	0.020

TABLE VI-8 (CONT)

Time at Start of Pulse Train	No. of Pulses	Total Length of Fire	Individual Pulse Width (secs)
546	1	0.02	0.020
548	25	2.5	0.100
553	2	0.1	0.050
556	1	0.05	0.050
563	16	1.6	0.100
567	2	0.1	0.050
569	1	0.05	0.050
572	1	0.05	0.050
579	25	2.5	0.100
582.2	1	0.05	0.050
583	1	0.05	0.050
587	1	0.05	0.050
592	11	1.1	0.100
596	1	0.05	0.050
599	1	0.05	0.050
601	1	0.05	0.050
602	2	0.10	0.050
604.2	1	0.05	0.050
606	1	0.05	0.050
609	1	0.05	0.050
610	1	0.05	0.050
619	1	0.05	0.050
620	1	0.02	0.050
629	1	0.02	0.020
643	1	0.02	0.020
649	1	0.02	0.020
657	1	0.05	0.050
665	1	0.02	0.020
679	1	0.02	0.020
698	16	1.6	0.100

TABLE VI-8 (CONT)

Time at Start of Pulse Train	No. of Pulses	Total Length of Fire	Individual Pulse Width (secs)
700.2	1	0.05	0.050
701	1	0.05	0.050
704	1	0.05	0.050
708	7	0.7	0.100
710	1	0.05	0.050
711	1	0.05	0.050
714	6	0.6	0.100
717	1	0.05	0.050
718	1	0.05	0.050
724	1	0.05	0.050
725	1	7.1	7.100
733	1	0.05	0.050
734.2	1	0.05	0.050
735	1	0.05	0.050
739	1	0.1	0.100
741	1	0.05	0.050
749	1	0.1	0.100
751	1	0.1	0.100
761	30	3.0	0.100
766	1	0.05	0.050
767	1	0.05	0.050
15 min			
1051	1	2.0	2.000
1057	16	1.6	0.100
1060	3	0.15	0.050
1064	1	0.05	0.050
1065	2	0.1	0.050
1069	8	0.8	0.100
1074	1	0.05	0.050
20 min			
1323	1	0.05	0.050
1327	1	0.05	0.050
1333	1	0.02	0.020
1338	2	0.1	0.050

TABLE VI-8 (CONT)

Time at Start of Pulse Train	No. of Pulses	Total Length of Fire	Individual Pulse Width (secs)
1340.2	1	0.05	0.050
1354	1	0.05	0.050
1359	1	0.05	0.050
1367.6	2	0.1	0.050
1374	1	0.02	0.020
1384	1	0.05	0.050
1394	1	0.02	0.020
1399	1	0.05	0.050
1409	1	0.05	0.050
1411	1	0.05	0.050
1415	1	0.05	0.050
1428.2	1	0.05	0.050
1431	1	0.05	0.050
1439	2	0.1	0.050
1443.4	1	2.25	2.250
1473	1	0.05	0.500
1475	1	2.5	2.500
1491	1	0.75	0.750
1505	1	0.75	0.750
1513	1	2.5	2.500
1569	2	0.1	0.050
1572	1	0.05	0.050
1579	1	0.05	0.050
1588	2	0.1	0.050
1592	1	0.02	0.020
1598	1	0.05	0.050
1604	1	0.02	0.020
1618.2	1	0.05	0.050
1620	1	0.05	0.050
1623	1	0.02	0.020
1629	1	0.05	0.050
1640	1	0.02	0.020
1645	1	0.05	0.050
1647.6	1	0.05	0.050
1652	1	0.02	0.020

TABLE VI-8 (CONT)

Time at Start of Pulse Train	No. of Pulses	Total Length of Fire	Individual Pulse Width (secs)
1658	1	0.05	0.050
1670	1	0.02	0.020
1684	1	0.02	0.020
1699	2	0.1	0.050
1708.4	1	0.05	0.050
1710	1	0.05	0.050
1713	1	0.02	0.020
1718	1	0.05	0.050
1723	1	0.05	0.050
1727.6	13	1.3	0.100
1734	2	0.1	0.050
1736	1	0.05	0.050
1753	1	0.05	0.050
1759	1	0.05	0.050
1761	1	0.05	0.050
1762.2	1	0.05	0.050
1767.6	2	0.1	0.050
1770.6	1	0.05	0.050
1777	2	0.2	0.100
1779.6	4	0.4	0.100
1784	1	0.05	0.050
1786	1	0.05	0.050
1789	1	0.05	0.050
1790.6	1	0.05	0.050
1793	1	0.05	0.050
1798	9	0.9	0.100
30 min			
1801.6	4	0.2	0.050
1807.6	6	0.6	0.100
1815	1	0.05	0.050
1817	3	0.3	0.100

TABLE VI-8 (CONT)

Time at Start of Pulse Train	No. of Pulses	Total Length of Fire	Individual Pulse Width (secs)
1821	4	0.4	0.100
1823	1	0.05	0.050
1824	1	0.05	0.050
1826	1	0.05	0.050
1827	9	0.9	0.100
1833	1	0.05	0.050
1835	1	0.05	0.050
1836	1	0.05	0.050
1840	6	0.6	0.100
1847	13	1.3	0.100
1851	6	0.6	0.100
1854	1	0.05	0.050
1855	1	0.05	0.050
1857	15	1.5	0.100
1860	20	2.0	0.100
1864	3	0.15	0.050
1867	1	0.05	0.050
1871	9	0.9	0.100
1874	2	0.2	0.100
1876.2	1	0.1	0.100
1877.8	2	0.2	0.100
1880.2	1	0.1	0.100
1881.8	1	0.1	0.100
1882.6	1	0.1	0.100
1884	1	0.1	0.100
1885.8	4	0.4	0.100
1890.2	3	0.3	0.100
1896	13	1.3	0.100
1903	6	0.6	0.100
1912.6	3	0.75	0.250
1927.4	3	0.75	0.250

TABLE VI-8 (CONT)

Time at Start of Pulse Train	No. of Pulses	Total Length of Fire	Individual Pulse Width (secs)
1943.8	1	0.25	0.250
1944.4	2	0.5	0.250
1946	2	0.5	0.250
1948.4	1	0.25	0.250

TABLE VI-9
PERFORMANCE DATA

Run No.	Data Pt sec	Data Pt min	Pulse Dur. at Data Pt. sec	w_f lb/sec	w_o lb/sec	w_T lb/sec	MR	P_c psia	c^*_T ft/sec	c^*_c ft/sec	I_{sp} sec	C_F	FPVIT °F	OPVIT °F
1704	Static												71	71
	1.0		1.25	0.132	0.216	0.347	1.64	82.3	5320	5255	291.0	1.76	64	66
	32.0		2.5	0.132	0.215	0.347	1.63	81.6	5281	5240	290.2	1.77	62	63
	359	(6)	15.0	0.132	0.214	0.346	1.62	81.1	5253	5250	291.7	1.79	54	54
	601	(10)	0.050										56	58
	726	(12)	7.1	0.131	0.214	0.345	1.63	81.1	5270	5245	293.8	1.79	58	59
	1052	(17 1/2)	2.0					80.4			286.3	1.78	61	66
	1323	(22 1/2)	0.050										70	74
	1514	(25.2)	2.5	0.132	0.213	0.345	1.62	80.2	5216	5190	289.3	1.78	56	58
	1802	(30)	0.050										59	60
	1947	(32 1/2)	0.250										57	59
	Heat Soak Back													
		1											70	75
		10											91	97
		20											108	117
		22											110	121

TABLE VI-10

PROTOTYPE ENGINE S/N 1 TEMPERATURE DATA

Run No.	Run Duration	Data Point	Inj. 1	Inj. 2	P.V. Flange 7	P.V. Fuel 8	P.V. Fuel 9	P.V. Ox. 10	P.V. Ox 11	Mfg. Flange 14, 15	F Gl
1694	15 1/2 Min	Static	73	74	72	71	71	87	72	74	
		1 Min	181	255	72	75	71	88	74	80	
		5 Min	607	668	80	93	71	97	79	159	
		10 Min	683	732	99	108	73	122	83	200	
		15 Min	713	766	112	114	73	126	85	220	
		15 1/2 Min	743	828							
	Heat Soak Back										
		1 Min	839	911	133	127	86	129	95	217	
		5 Min	688	724	187	184	119	149	132	265	
		10 Min	566	593	210	210	150	166	150	276	
		20 Min	455	472	214	218	174	176	166	265	
		30 Min	394	407	207	211	178	175	168	248	
		40 Min	352	362	198	203	176	170	167	231	
					(Did not Purge Between this Test and Next)						
1695	17 1/2 Min	Static	213	218	156	158	151	144	148	168	
		1 Min	330	419	138	130	100	128	102	159	
		5 Min	751	829	130	127	90*	145	95	213	
		10 Min	817	902	177	142	90*	170	98	270	
		15 Min	843	925	193	151	90*	176	102	299	
		17 Min	852	935	202	153	90*	176	104	306	
	Heat Soak Back										
		1 Min	972	1048		163	121	171	118	290	
		5 Min	810	851		235	153	167	156	305	
		10 Min	678	707	175	268	191	171	180	300	
		20 Min	551	572	188	278	224	180	219	289	
		30 Min	481	498	195	272	233	181	227	274	
		40 Min	435	449	195	260	231	177	226	257	
					(Purged Between this Test and Next)						
1696	26 Min	Static	68	74		25	34	38	24	44	
		10 Min	170	210							
		26 Min	289	334		39	45	44	44	82	
	Heat Soak Back										
		10 Min	241	254		58	30	39	29	79	
1697	5 Sec	5 Sec				64	39	39	50	79	
1698	10 Min	10 Min			56	54	57	70	55	58	
1699	10 Min	10 Min			58	55	56	71	57	61	
1700	10 Min	10 Min			61	58	61	74	60	62	
1701	10 Min	10 Min			61	58	62	74	62	65	
1702	4 Min	4 Min			61	62	61	74	62	64	
1703	5 Sec	5 Sec			61		62	76	62	64	
1704	32 1/2 Min	Static	108	109	75	86	80	88	82	86	
		≈6 Min	647	651	81	102	63	100	66	165	
		≈10 Min	790	869	103	111	63	122	70	209	
		≈22 1/2 Min	693	711	115	194	121	136	84	236	
		≈30 Min	677	683	113	126	72	75	78	236	
		32 1/2 Min	794	838	136	120	70	95	76	255	
	Heat Soak Back										
		1 Min	852	877	131	174	146	97	108	251	
		10 Min	591	604	131	220	154	103	168	248	
		20 Min	479	489	141	220	178	156	184	236	
		22 Min	464	474	141	219	179	157	184	234	
						Chamber Inspected - OK					

*Data Questionable

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ulation Temp.		Columbium Shell Temp.					Ring Support		Structural Support		P.V. Cover		
19	25	20	21	22	23	24	3	4	5	6	12	13	Type of Run
74	72	71	76	74	74	73	74	73	73	72	71	72	3000 Pulses 0.030 on 0.270
74	73	71	76	82	89	93	181	155	104	97	85	77	off
109	92	89	110	440	496	512	488	438	310	256	137	94	
280	232	229	228	772	791	840	565	530	389	316	156	107	
479	422	419	366	964	962	1019	614	578	429	345	168	114	
503	446	442	383	981	979	1043	613	584	435	314	168	115	
535	477	473	406	1004	988	1059	627	609	450	315	169	115	
639	586	583	486	968	928	986	550	548	444	278	154	124	
692	651	651	533	888	844	891	472	477	399	247	157	142	
666	641	644	521	765	730	767	393	400	345	225	164	161	
598	580	583	474	666	641	670	347	354	310	211	165	166	
530	516	519	425	584	565	589	312	319	282	197	162	164	
286	281	281	244	312	305	315	195	197	183	150	139	143	1000 Pulses 0.100 on 0.90
284	277	278	242	314	311	331	315	278	215	183	155	144	off
303	284	281	265	673	705	762	623	554	420	341	202	140	
558	406	402	367	1002	1015	1071	705	637	502	408	221	148	
	581	580		1183	1176	1243	738	678	533	435	229	155	
	648	648		1235	1223	1298	751	692	542	444	232	158	
	707	228		1258	1242		751	725	562	425	224	156	
	792			1190	1146		661	659	546	384	197	163	
	832			1087	1039		574	580	493	344	196	178	
	789			929	893		481	491	427	309	210	207	
				805	779		426	435	385	284	212	215	
				713	693		388	396	354	262	209	214	
	145			87	86	153	69	69	65	44			150 Pulses 0.100 on
	218			225	219	218	155	149	122	83			9.9 off
	235			428	397	451	234	232	174	119			
	131			421	381	203	193	199	164	101			
													Check Run
													10 Pulses 0.010 on 60.0 off
													10 Pulses 0.020 on 60.0 off
													10 Pulses 0.030 on 60.0 off
													10 Pulses 0.040 on 60.0 off
													4 Pulses 0.010 on 60.0 off
													Check Run
				149	144	158	101	102	97	85	79	81	Apollo C.M. Duty Cycle
				462	467	350	478	456	332	223	102	83	Minimum on Time of
				732	731	479	652	573	437	301	139	93	0.020 sec
				886	848	521	551	544	454	294	143	117	Maximum on Time of
				950	916	514	564	552	427	322	137	107	15.0 sec
				988	964		653	611	450	344	165	111	
				1057	1043		655	641	505	350	162	114	
				1026	986		493	500	423	287	160	145	
				840	801		413	421	362	259	168	167	
				818	781		401	410	353	255	169	169	

TABLE VI-10 (CONT)

Run No.	Data Point	Flg. 15	Stand		Fiberglass					Inj. Flg. 33	Fiberglass			
			16	17	26	27	30	31	32		34	35	36	38
1694	Static	72	71	72	72	70	69	68	68	72	71	72	75	73
	1 Min	83	76	74	77	88	91	96	122	74	96	114	87	138
	5 Min	207	97	81	106	133	150	169	229	96	159	213	136	262
	10 Min	285	125	89	150	162	188	233	281	116	184	268	170	311
	15 Min	328	148	98	185	176	217	274	307	124	196	291	181	330
	15 1/2 Min	333	150	99	190	177	220	276	306	126	197	292	183	328
	Heat Soak Back													
	1 Min	343	152	99	193	172	216	271	290	146	187	275	178	310
	5 Min	347	158	100	200	157	193	243	246	236	158	232	156	262
	10 Min	322	160	103	203	148	177	212	211	265	146	201	141	222
	20 Min	288	158	105	199	147	165	168	171	263	150	167	135	177
	30 Min	262	154	106	190	146	154	148	149	248	152	147	135	158
	40 Min	241	150	106	181	142	143	134	136	232	148	135	133	145
1695	Static	165	123	100	139	111	105	100	104	168	115	105	111	112
	1 Min	169	127	103	142	123	120	118	143	146	134	139	122	162
	5 Min	299	149	112	171	169	175	192	262	125	196	244	177	300
	10 Min	367	176	123	223	208	226	272	331	145	233	312	218	370
	15 Min	406	204	135	265	228	260	314	353	156	254	341	241	393
	17 Min	419	213	140	278	235	271	322	361	159	259	346	247	397
	Heat Soak Back													
	1 Min	436	217	141	285	230	269	314	341	183	251	324	244	371
	5 Min	436	218	142	283	205	240	280	284	300	208	266	206	303
	10 Min	406	217	144	276	187	218	242	239	335	187	226	178	250
	20 Min	362	208	144	260	176	194	188	186	331	183	181	165	197
	30 Min	330	198	143	244	170	176	163	164	315	180	162	160	170
	40 Min	306	189	141	230	167	166	148	150	300	174	150	156	160
1696	Static	62	32	67	71	71	70	70	71	44	71	72	75	74
	10 Min	87	27	59	78	90	96	107	126	56	96	117	97	135
	26 Min	130	31	58	96	105	124	147	166	63	112	156	110	175
	Heat Soak Back													
	10 Min	133	35	55	93	97	119	136	139	92	102	138	98	145
1704	Static	88	71	63	78	70	70	69	70	91	73	72	73	75
	6 Min	238	86	65	98	87	89	99	122	126	94	113	93	142
	10 Min	302	105	70	123	111	120	150	206	129	128	189	118	250
	22 1/2 Min	345	135	76	173	120	142	180	201	257	119	187	122	226
	30 Min	347	145	81	187	131	154	179	206	155	138	192	128	235
	32 1/2 Min	348	152	86	197	152	172	205	256	136	170	241	150	293
	Heat Soak Back													
	1 Min	391	158	87	212	162	183	212	245	200	172	224	164	276
	10 Min	346	161	90	214	148	164	180	188	277	151	178	144	208
	20 Min	305	156	92	204	142	152	152	156	266	148	150	136	170
	22 Min	298	155	92	201	142	150	147	151	264	148	147	136	165

Run No.	Duration (second)	P_c (nominal) (psia)	Mixture Ratio (nominal)
1707	20	80	1.4
1708	20	80	1.4
1709	20	80	1.8
1710	20	80	1.8
1711	20	70	1.6
1712	20	70	1.6
1713	20	90	1.6
1714	20	90	1.6

A summary of the performance data for these tests is given in Table VI-11.

(4) Accumulated Time and Performance Series (Run Nos. 1715-1722)

These eight tests were made to accumulate time on the engine assembly in short duration, steady state firings. The low capacity steam ejector system was used for this series. Due to operational problems with the steam supply boilers the pressure in the altitude chamber varied throughout each test and resulted in various run durations and various off times between each run. These tests consisted of the following:

Run No.	Duration (second)	Off Time (minutes)	P_c (nominal) (psia)	Mixture Ratio (nominal)
1715	12		80	1.6
1716	15		80	1.6
1717	10		80	1.6
1718	10		80	1.6
1719	10		80	1.6
1720	7		80	1.6
1721	10		85	1.6
1722	7		85	1.6

TABLE VI-11

S/N 1 ENGINE DATA

Run No.	Dur. sec	Data Pt sec	P_{c_T} psia	M.R.	c^*_T ft/sec	c^*_c ft/sec	F_∞ lb	$I_{sp\infty}$ sec	$C_{F\infty}$
1705	10	9.5	81.4	1.58	5300	5300	102.2	296.3	1.76
1706	10	9.5	81.3	1.56	5310	5310	100.3	291.8	1.77
1707	20	10	80.9	1.41	5375	5375	99.9	295.7	1.77
		20	80.4	1.40	5330	5355	100.0	295.4	1.78
1708	20	10	80.1	1.41	5315	5315	99.7	294.9	1.78
		20	79.8	1.39	5320	5345	99.6	295.8	1.79
1709	20	10	79.0	1.77	5205	5205	97.7	286.8	1.77
		20	78.3	1.75	5180	5205	97.7	287.7	1.79
1710	20	10	78.4	1.76	5175	5175	97.8	287.8	1.79
		20	78.1	1.74	5190	5215	97.8	289.5	1.79
1711	20	10	70.2	1.61	5320	5320	86.5	292.1	1.77
		20	69.6	1.61	5275	5300	86.4	291.7	1.78
1712	20	10	69.6	1.61	5255	5255	86.6	291.3	1.78
		20	69.3	1.59	5270	5295	86.3	292.8	1.79
1713	20	10	88.6	1.61	5215	5215	-	289.0	1.78
		20	88.1	1.58	5215	5240	-	291.1	1.80
1714	20	10	88.2	1.57	5230	5230	-	292.8	1.80
		20	88.1	1.55	5255	5280	-	294.8	1.80

Throughout Run Nos. 1721 and 1722 an increase of approximately five psi was noted in chamber pressure with no apparent change in flow rate. Run No. 1722 was terminated prematurely at seven seconds due to a rapid decrease in chamber pressure. It should be noted that the off time following Run Nos. 1720 and 1721 were 20 and 10 minutes, allowing heat soak back.

Performance data for these tests are given in Table VI-12.

(5) Post-Run Inspection

Post-run inspection of the engine assembly disclosed a burnout in the chamber section at approximately the 1:00 o'clock position. The burnout was approximately one inch in diameter and two inches from the injector. The burnout caused damage to the alumina bubble insulation, the columbium shell, the "Dyna-Quartz" insulation, and the fiberglass wrap at the injector end of the assembly. Another small burnout region about 1/8 inch in diameter was noted in the chamber section at approximately the 3:00 o'clock position. No damage had occurred to the insulation material in this area of the chamber. Metal was deposited at the throat station apparently accounting for at least a portion of the chamber pressure increase noted during the last two tests.

Figure VI-68 through VI-69 show the condition of the engine assembly on the test stand following the test series.

The assembly was removed from the test stand, disassembled and inspected. The bipropellant valve was removed from the assembly and was flushed and dried. The injector assembly was machined from the chamber, inspected under magnification and water flowed.

Figures VI-70 through VI-75 reveal various parts of the engine assembly during disassembly and inspection. Additional observations made during this inspection were as follows:

(1) The compatibility between the alumina bubbles and the silicide coated columbium and the Dyna-Quartz insulation and the silicide coated columbium was again excellent as noted on the first engine assembly.

TABLE VI-12

S/N 1 ENGINE DATA

Run No.	Dur sec	Data Pt sec	P_{c_T} psia	M.R.	c^*_T ft/sec	c^*_c ft/sec	F_∞ lb	$I_{sp\,\infty}$ sec	$C_{F\,\infty}$
1715	12	12	79.6	1.61	5270	5280	97.5	287.5	1.76
1716	15	10	79.7	1.60	5280	5280	98.5	290.9	1.77
		15	79.5	1.60	5240	5260	98.0	287.8	1.77
1717	10	10	79.8	1.60	5250	5250	98.6	289.1	1.77
1718	10	10	79.8	1.60	5275	5275	98.7	290.5	1.77
1719	10	10	79.8	1.59	5285	5285	99.3	293.0	1.78
1720	7	5	80.2	1.60	5270	5265	99.3	290.8	1.78
1721	10	10	85.2	1.57	5673 (1)	5673 (1)	102.0	302.8	1.72
1722	7	6	85.1	1.56	5664 (1)	5659 (1)	101.4	300.6	1.71

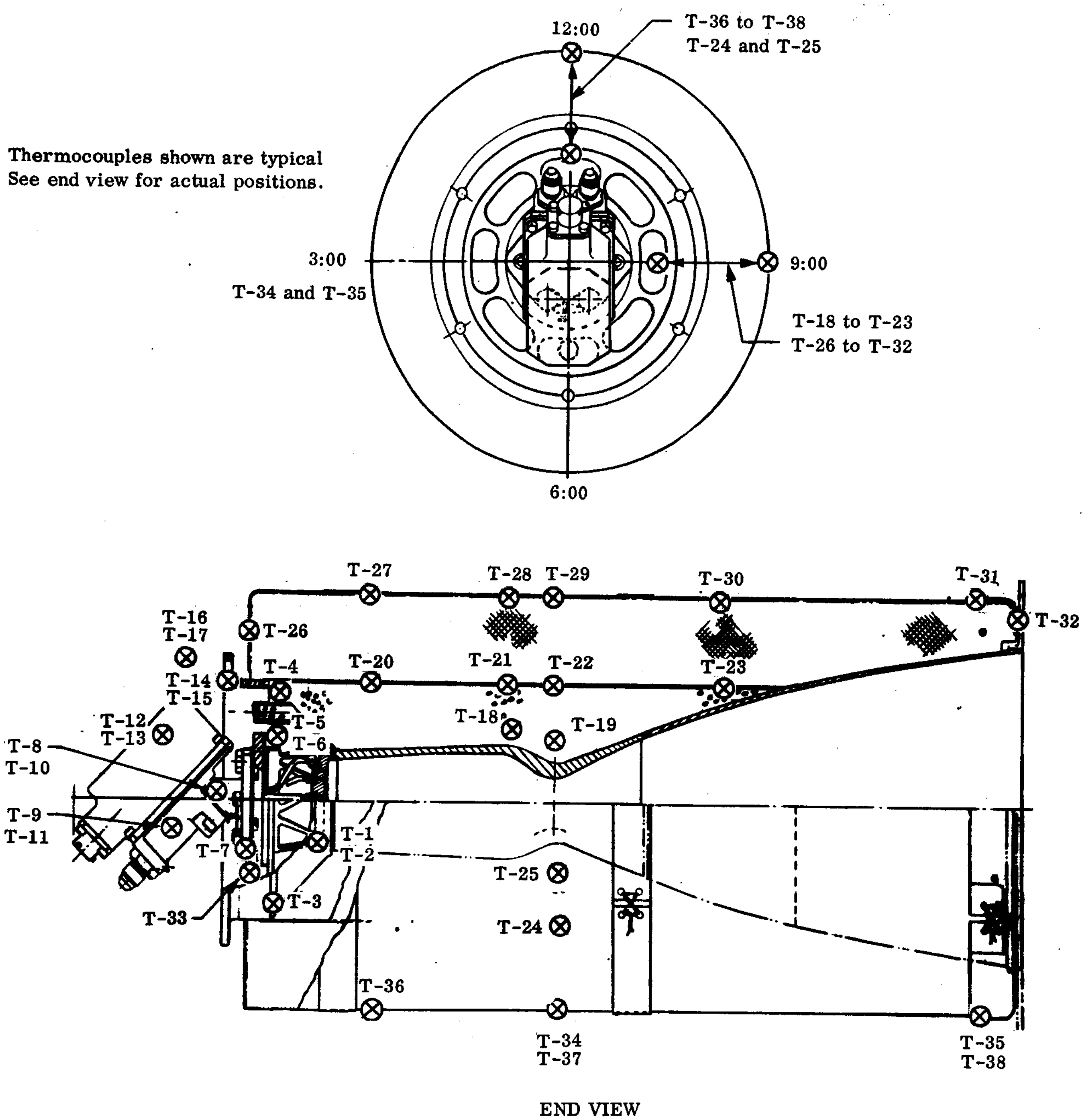
(1) Questionable

There were areas around the erosion and burnout region where the alumina bubbles had partially melted and reacted with the chamber coating and base material. This reaction, however, was caused by the extremely high temperatures that existed due to the apparent high heating rates in the erosion and burnout regions and the gas flow past the alumina bubbles once burnout occurred.

(2) Considerable erosion was noted in the chamber section.

(3) The injector appeared in good condition and during inspection under 30 x magnification revealed all orifices were clear. The face of the injector had a white-grey discoloration. Very little oxidation scale was noted at the oxidizer orifices. A water flow revealed all the orifices were flowing freely. The pressure drop of the fuel side had increased 3 psi, the oxidizer drop indicated a decrease of 3 psi. An impingement check revealed similar characteristics to those obtained during prefire impingement flows. The fans developed by three of the eight elements showed discrepancies considered undesirable. The identification of the injector impingement is shown in Figure VI-76.

(4) The propellant valve was leak tested with N_2 gas at 300 psig for 5 minutes, revealing no leakage on either the fuel or oxdizer side.



T-1	Injector Temp	T-14	Flange Temp	T-26	Fiberglass Temp
T-2	Injector Temp	T-15	Flange Temp	T-27	Fiberglass Temp
T-3	Ring Support Temp	T-16	Stand Temp	T-28	Fiberglass Temp
T-4	Ring Support Temp	T-17	Stand Temp	T-29	Fiberglass Temp
T-5	Structural Support Temp	T-18	Insulation Temp (1/4 in. from wall)	T-30	Fiberglass Temp
T-6	Structural Support Temp	T-19	Insulation Temp (1/4 in. from wall)	T-31	Fiberglass Temp
T-7	P.V. Flange Temp	T-20	Columbium Shell Temp	T-32	Fiberglass Temp
T-8	P.V. Fuel Body Temp	T-21	Columbium Shell Temp	T-33	Injector Flange Temp
T-9	P.V. Fuel Body Temp	T-22	Columbium Shell Temp	T-34	Fiberglass Temp
T-10	P.V. Oxidizer Body Temp	T-23	Columbium Shell Temp	T-35	Fiberglass Temp
T-11	P.V. Oxidizer Body Temp	T-24	Columbium Shell Temp	T-36	Fiberglass Temp
T-12	P.V. Cover Temp	T-25	Insulation Temp (1/4 in. from wall)	T-37	Fiberglass Temp
T-13	P.V. Cover Temp			T-38	Fiberglass Temp

Figure VI-26. Thermocouple Location - Prototype Engine Assemblies S/N 2 & 1

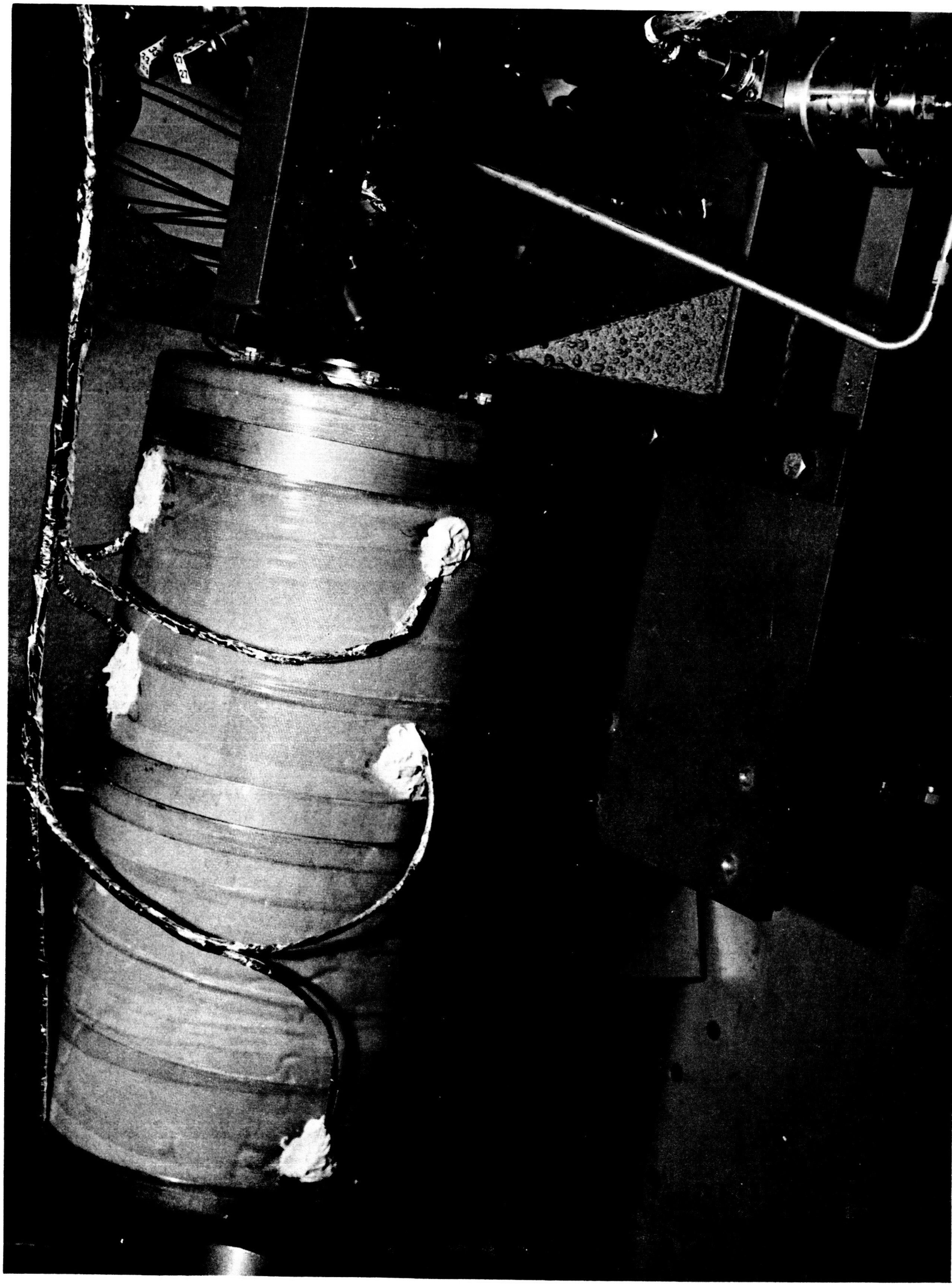


Figure VI-27. Thermocouple Installation with Engine Assembly on Test Stand

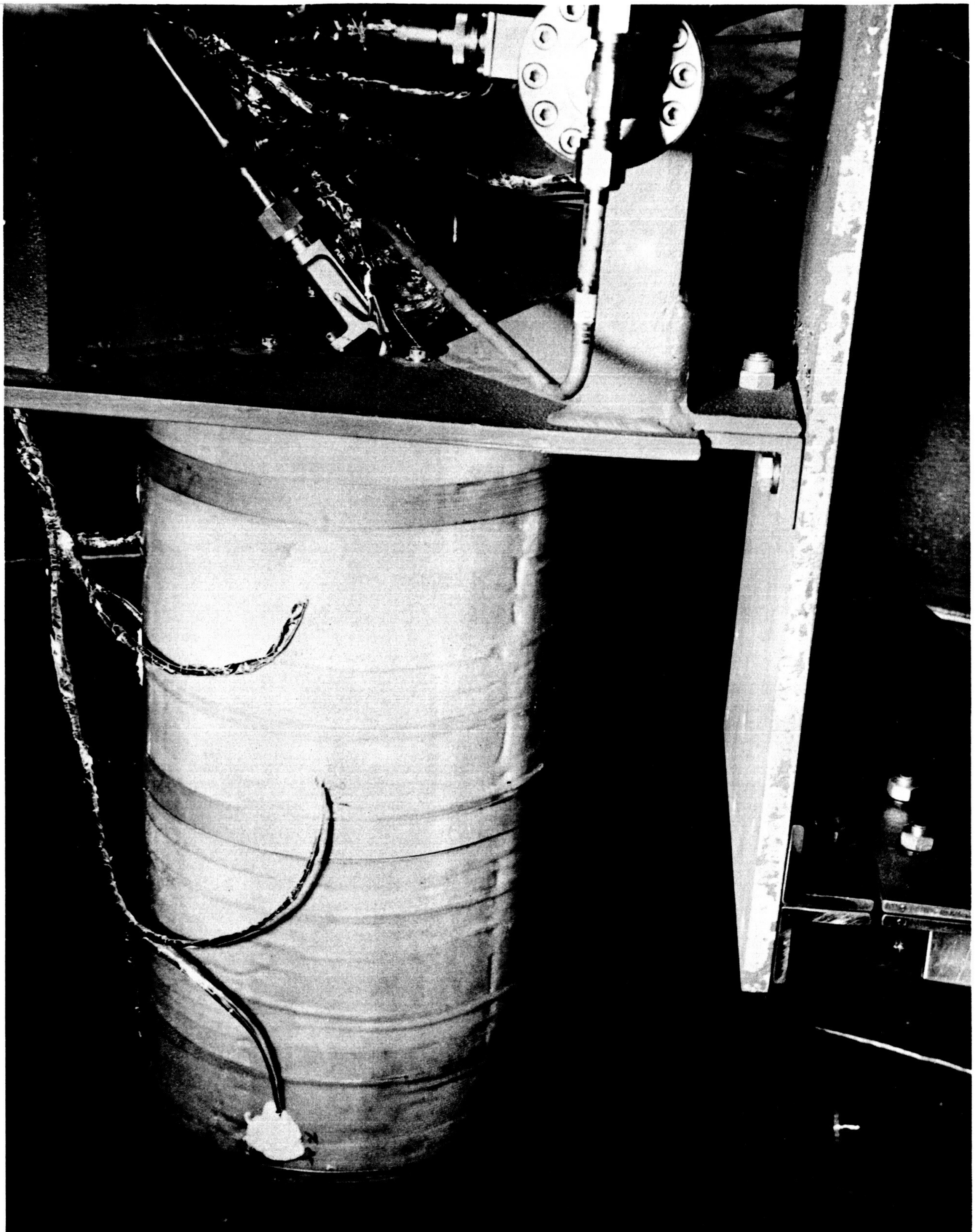


Figure VI-28. Thermocouple Installation with Engine Assembly on Test Stand

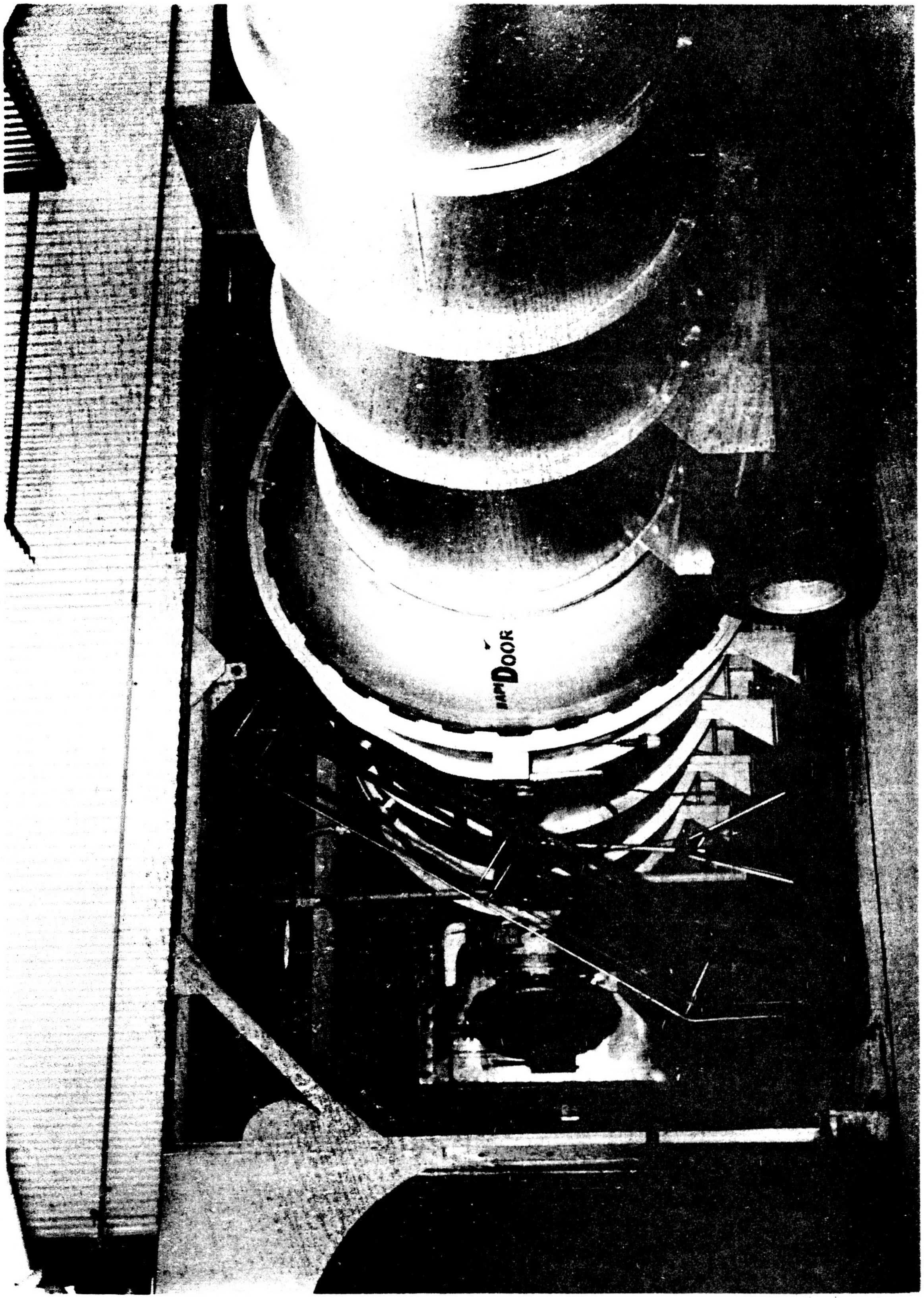


Figure VI-29. Altitude Test Chamber, Hardware Test Section

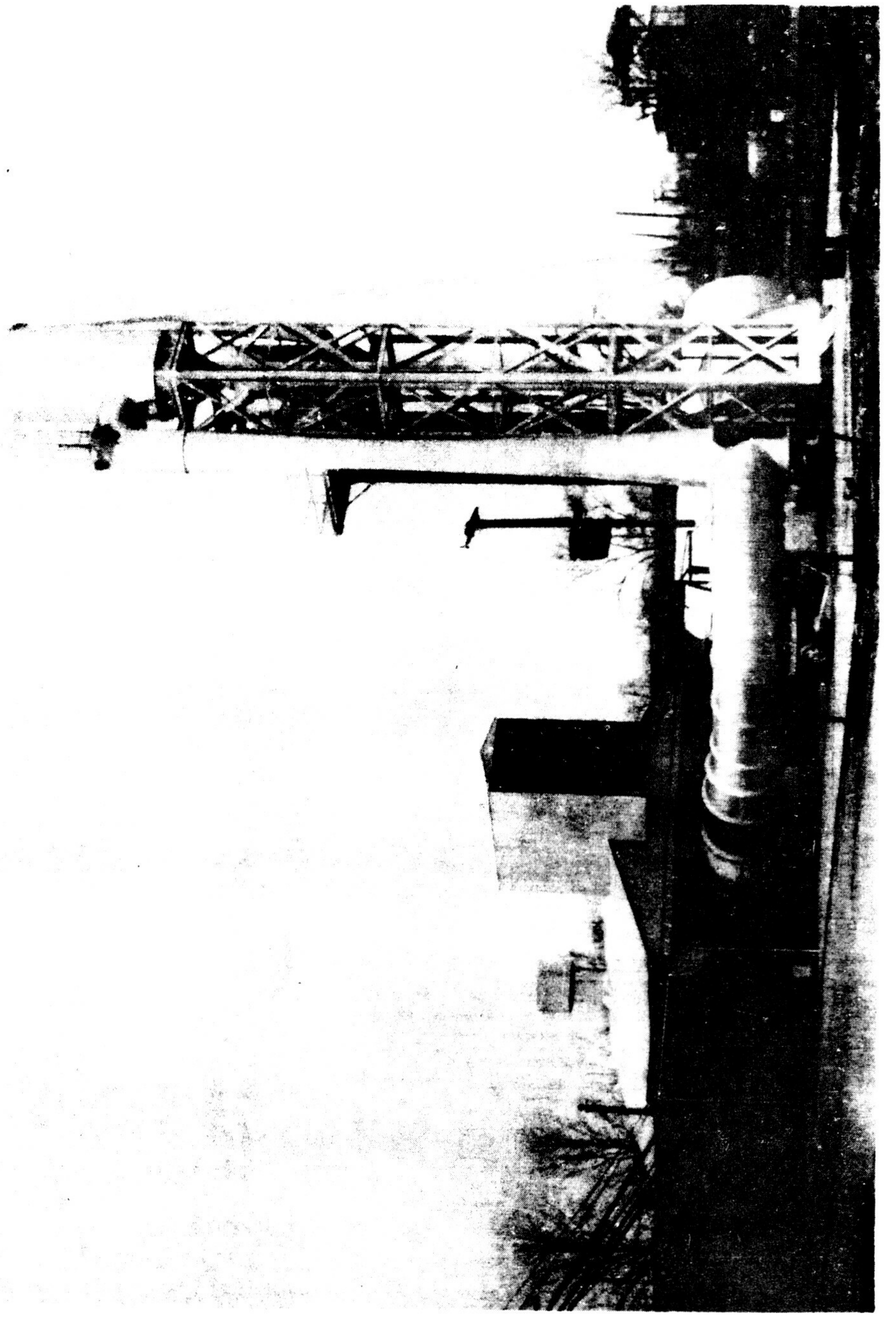


Figure VI-30. View of Steam Ejector

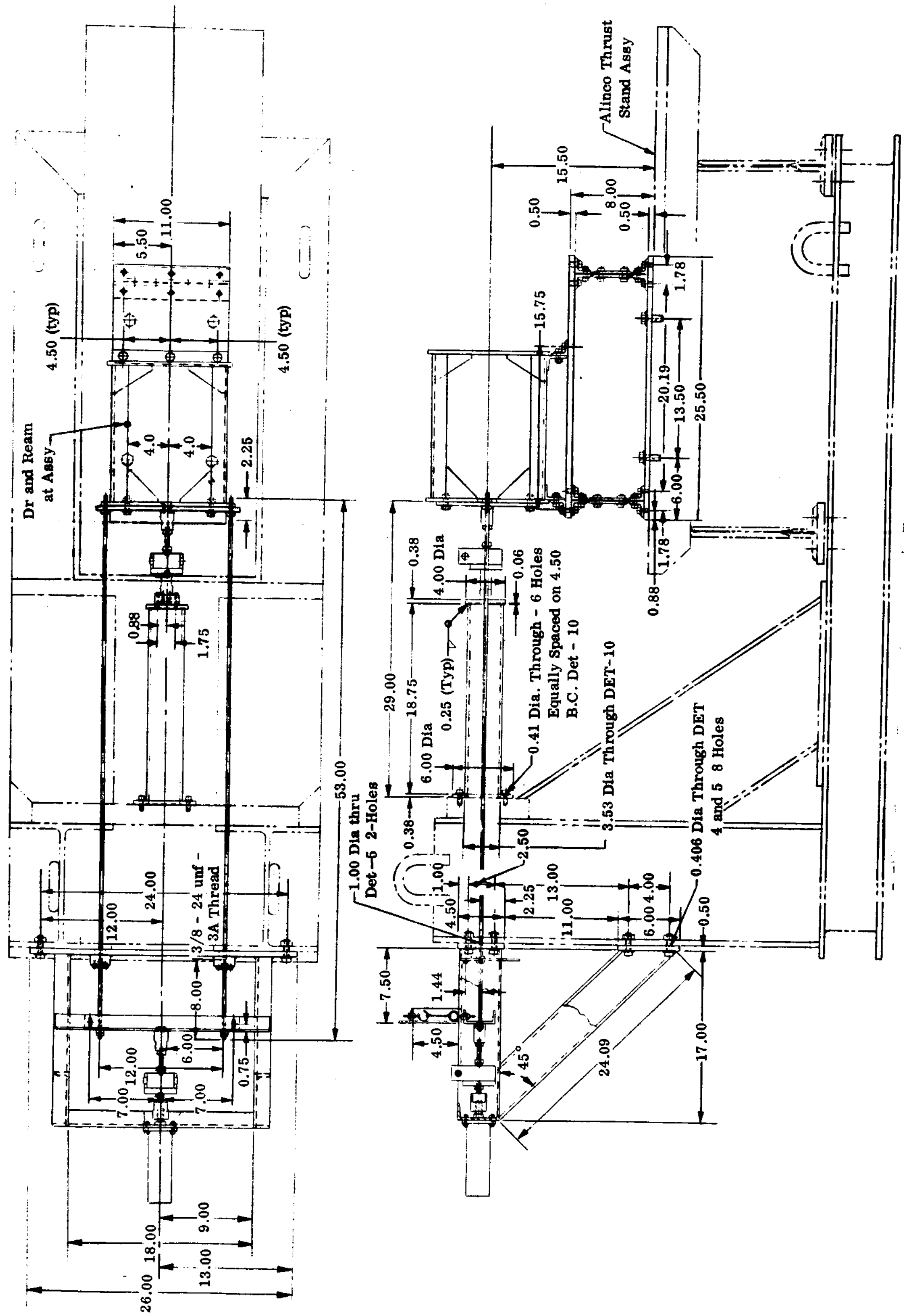
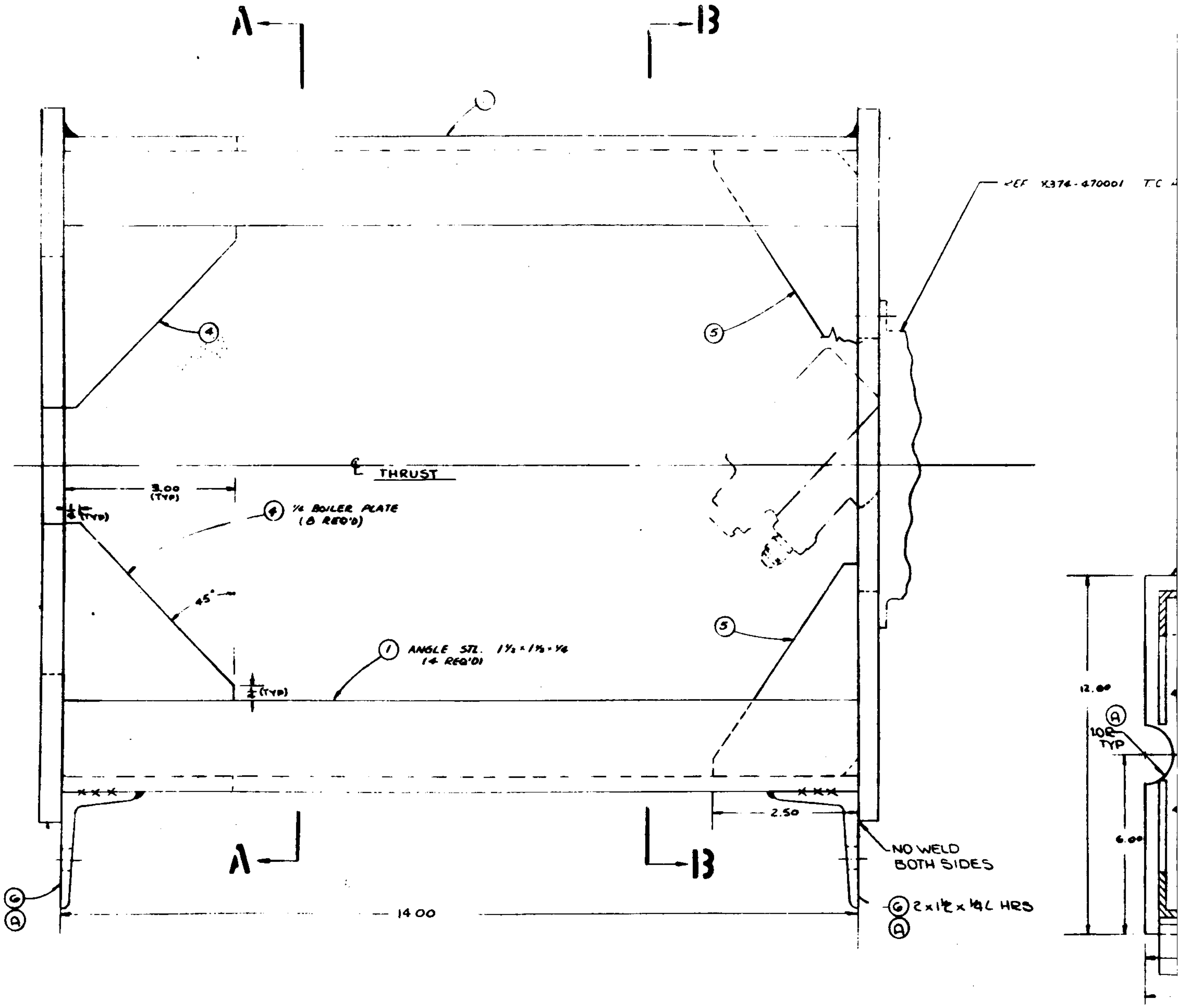


Figure VI-31. Thrust Measuring and Calibrating Installation



A
B
REF X374-470001 T.C
4
5
℄ THRUST
3.00 (TYP)
4 1/4 BOILER PLATE (8 REQ'D)
45°
1 ANGLE STL. 1½ × 1½ × 1/4 (4 REQ'D)
2.50
NO WELD BOTH SIDES
6 2 × 1½ × 1/4 L HRS
A
14.00
12.00
6.00
10R TYP

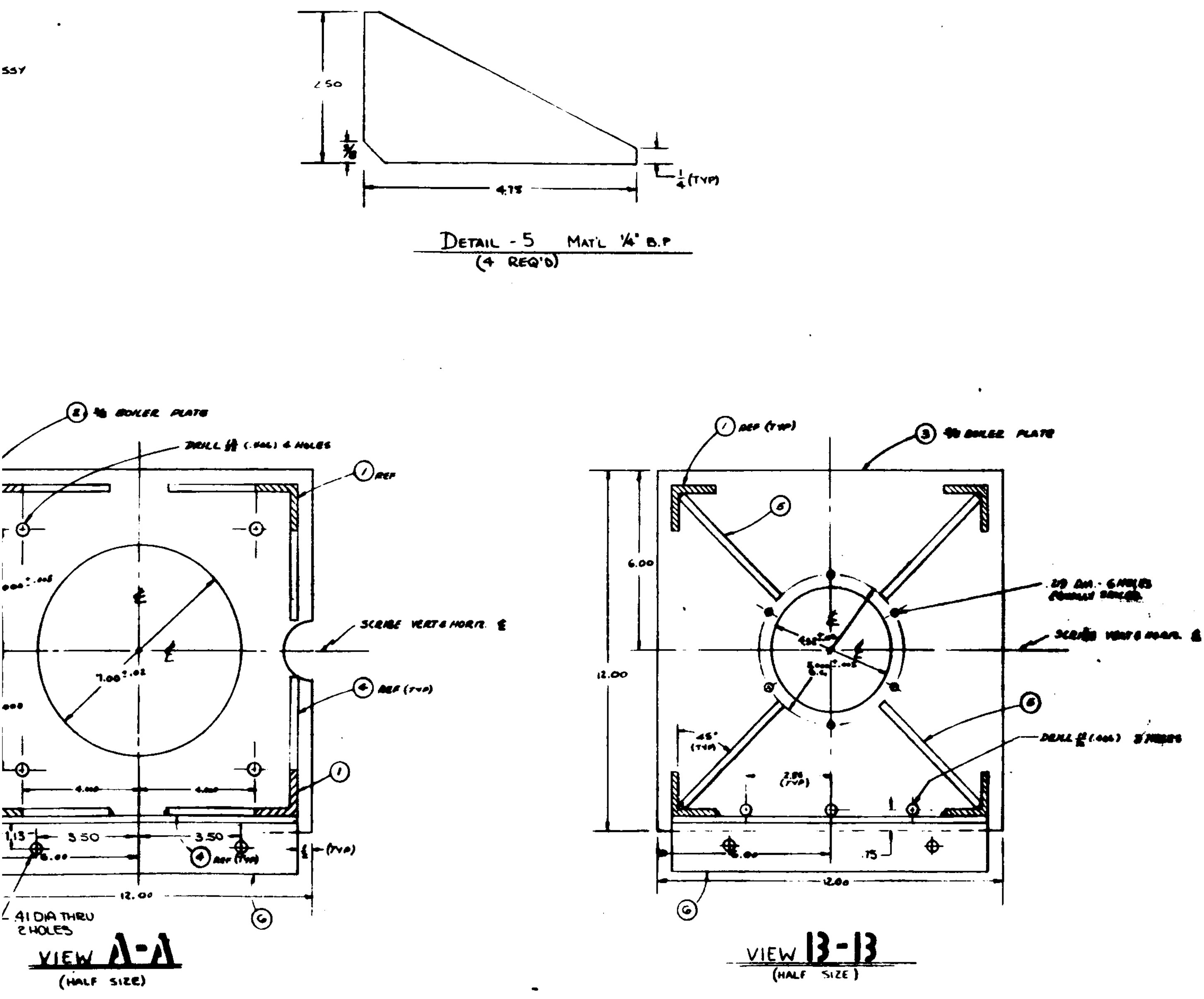
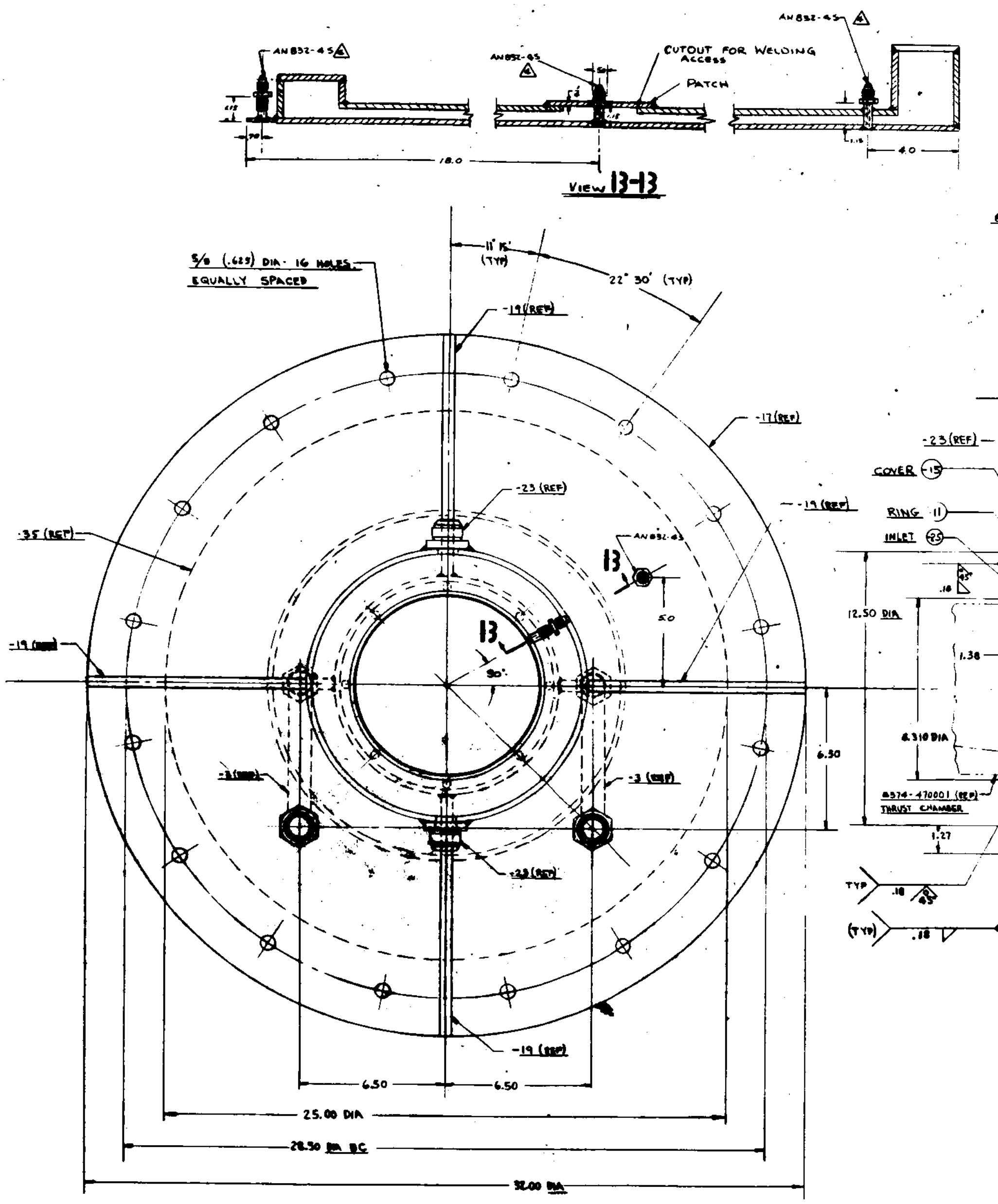
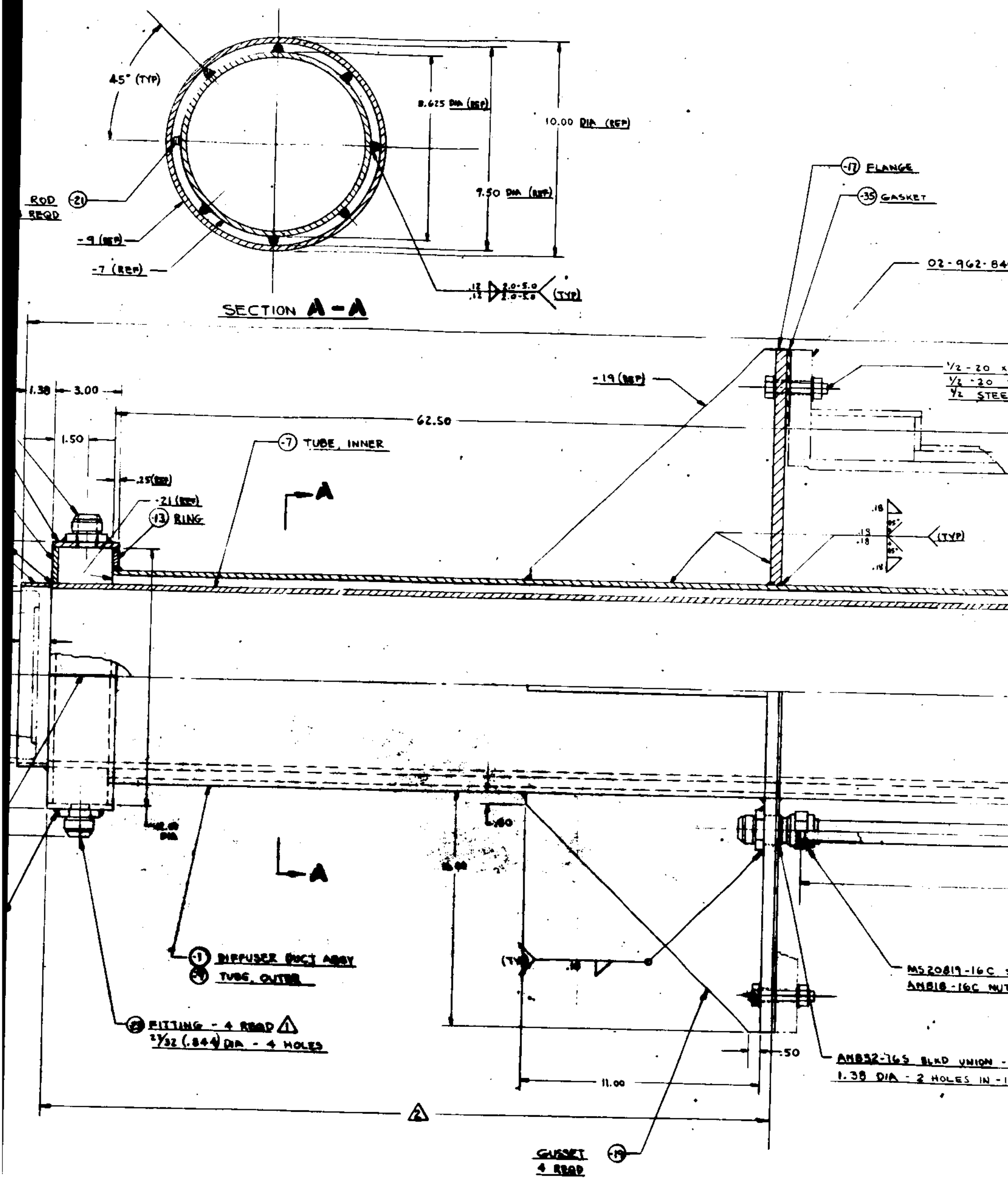


Figure VI-32. Thrust Chamber Mount Assembly


AN832-4S
CUTOUT FOR WELDING ACCESS
PATCH
18.0
4.0
VIEW B-B
5/8 (.625) DIA - 16 HOLES EQUALLY SPACED
11° 15' (TYP)
22° 30' (TYP)
-19 (REF)
-17 (REF)
-23 (REF)
-35 (REF)
-3 (REF)
COVER 15
RING 11
INLET 25
12.50 DIA
6.310 DIA
8374-470001 (REF) THRUST CHAMBER
6.50
25.00 DIA
28.50 DIA BC
32.00 DIA
TYP
(TYP)

BELL AEROSYSTE



DUCT PRESS. PICK UP

HYDRO TEST TO PSIG

DIMENSION TO BE DETERMINED

MAKE -23 FITTING FROM AN815-16S UNION

NOTES -

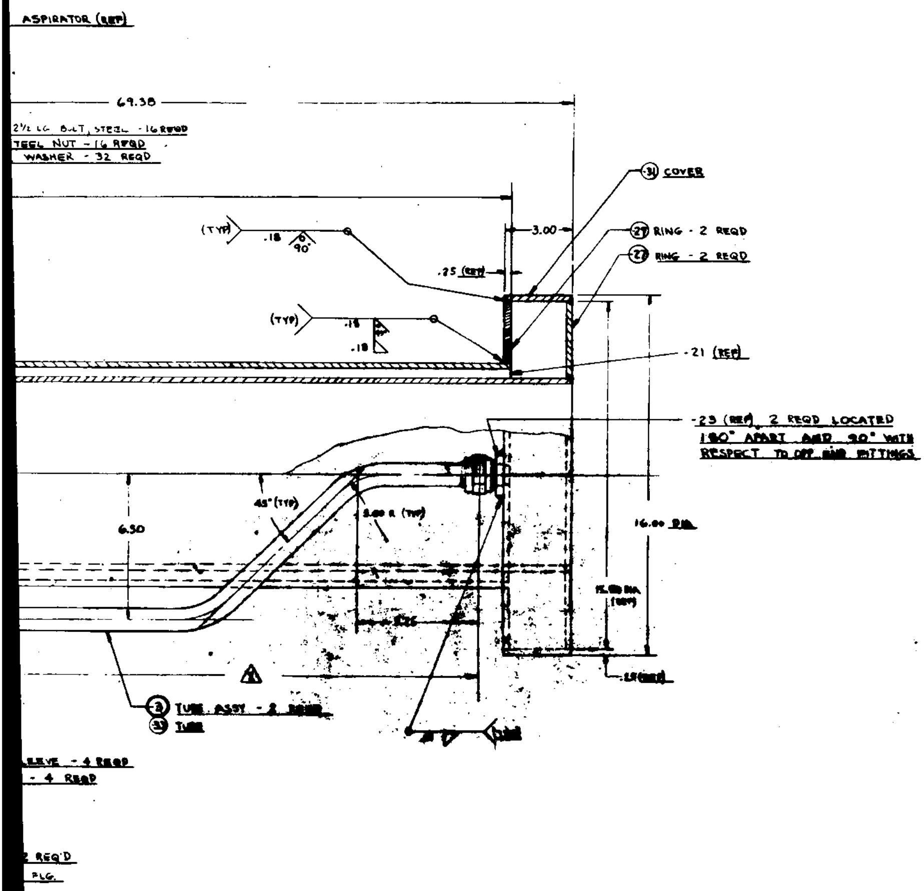
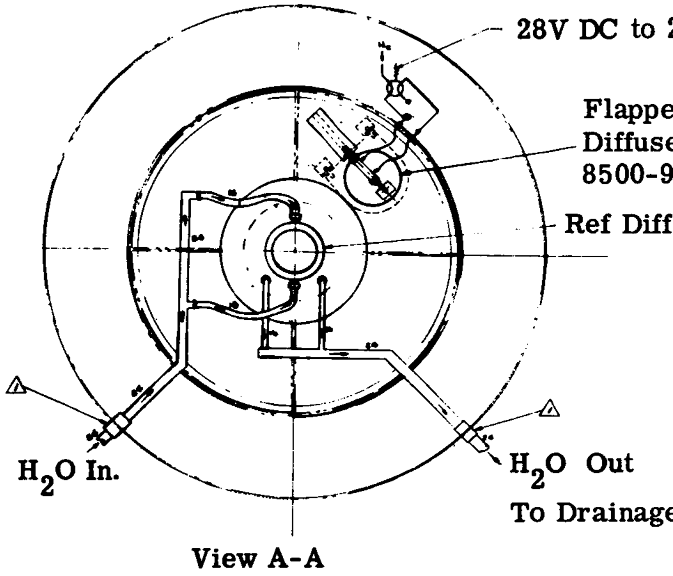
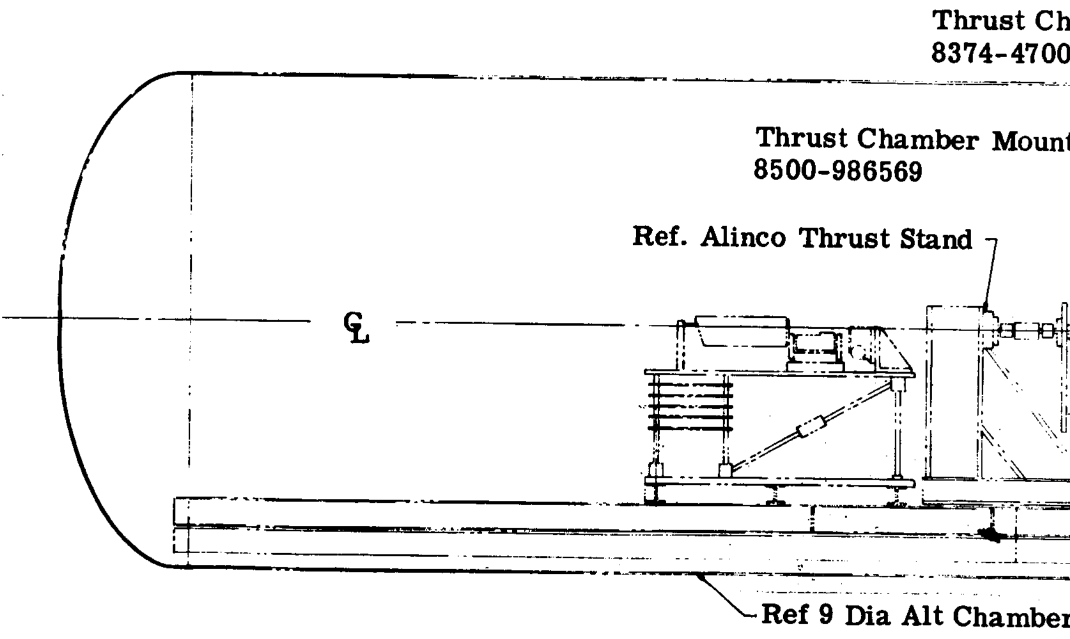


Figure VI-33. Diffuser Duct Assembly


28V DC to
Flappe
Diffuse
8500-9
Ref Diff
H_2O In.
H_2O Out
To Drainage
View A-A


Thrust Ch
8374-4700
Thrust Chamber Mount
8500-986569
Ref. Alinco Thrust Stand
℄
Ref 9 Dia Alt Chamber

E Control Rm

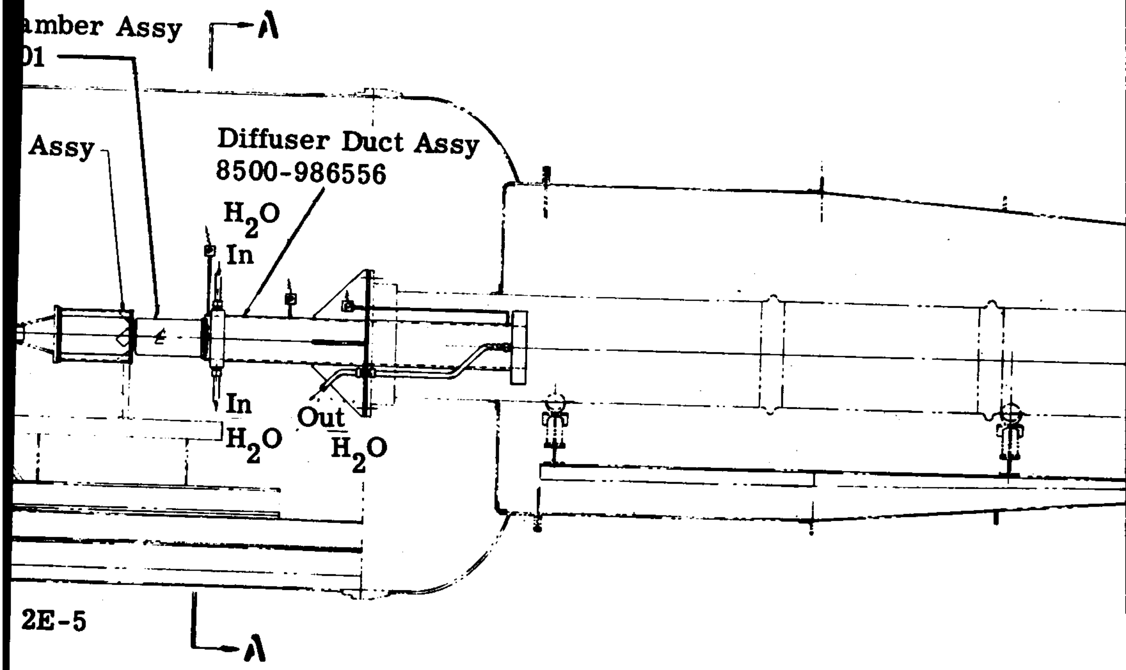
r Valve Instl
r Duct By Pass
36560

user Duct

NOTES:

Ditch

1 Systems 2" Pipe Coupling into



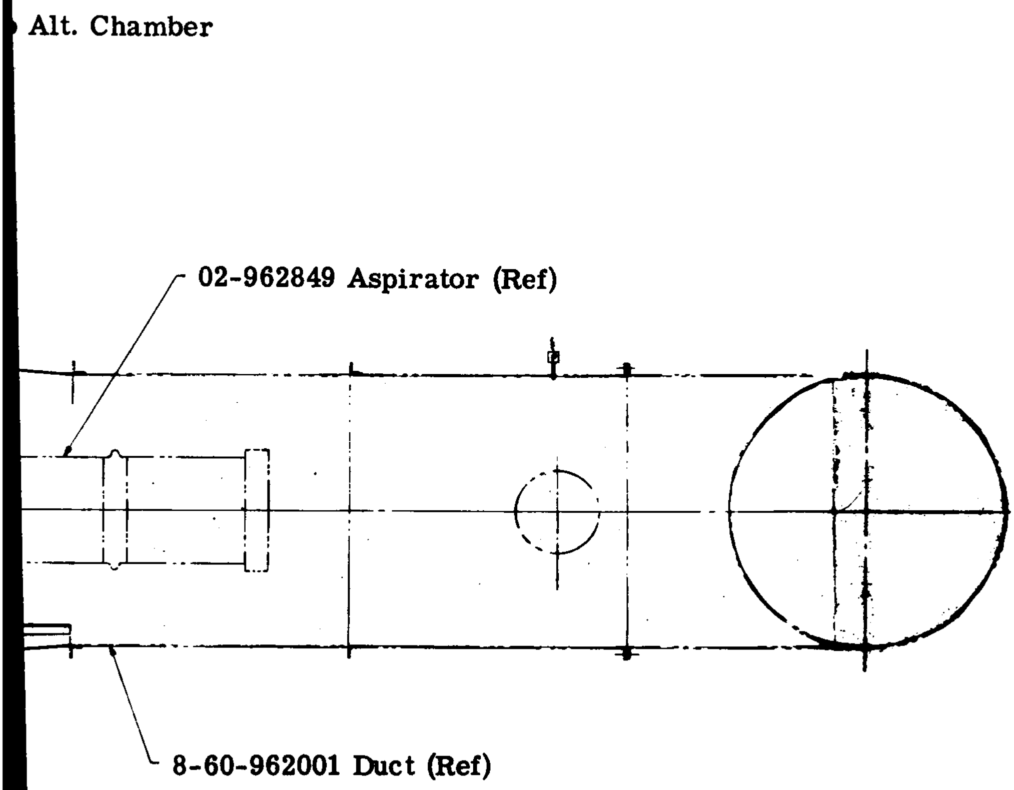


Figure VI-34. Thrust Chamber Installation on Sta

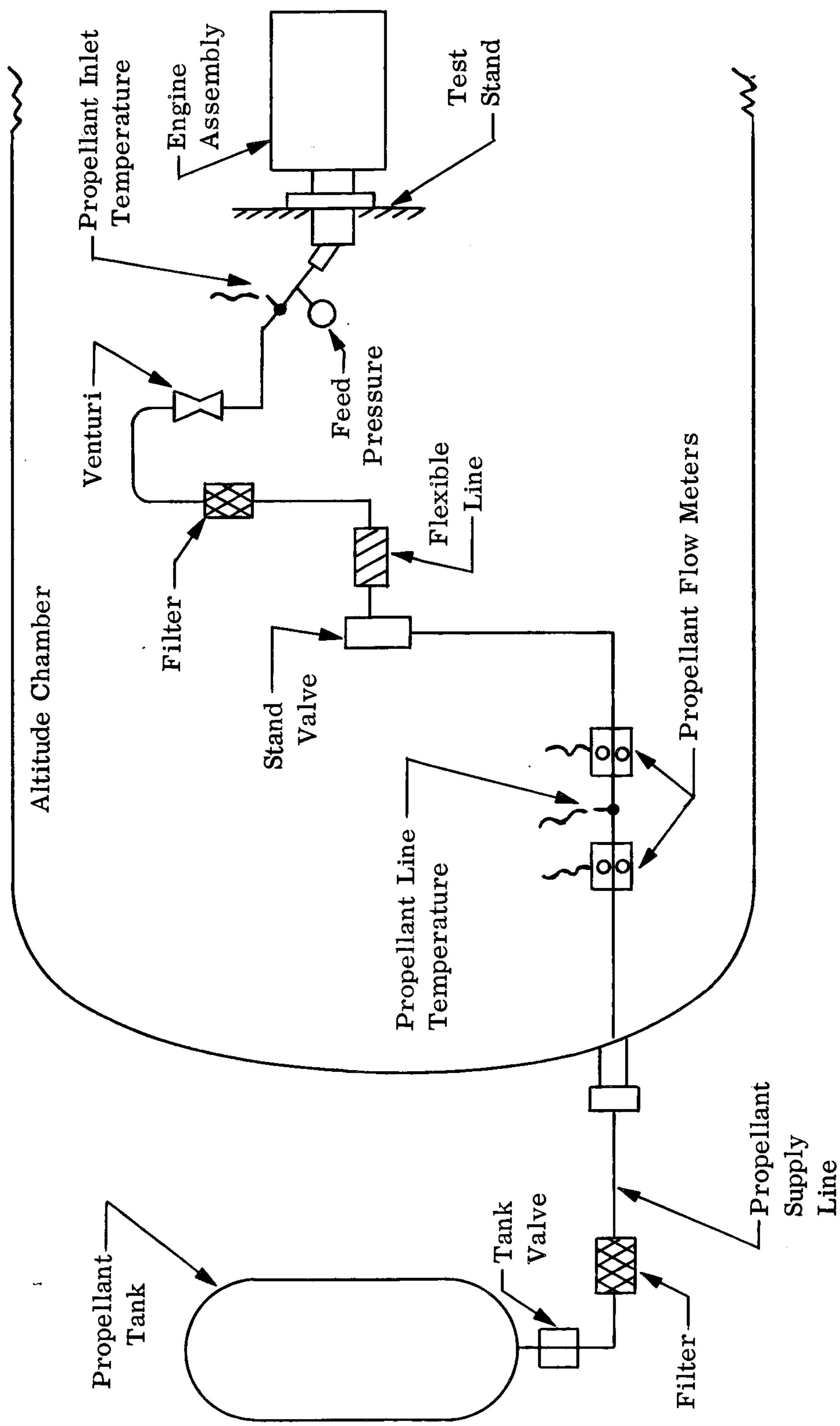


Figure VI-35. Typical Altitude Cell Schematic

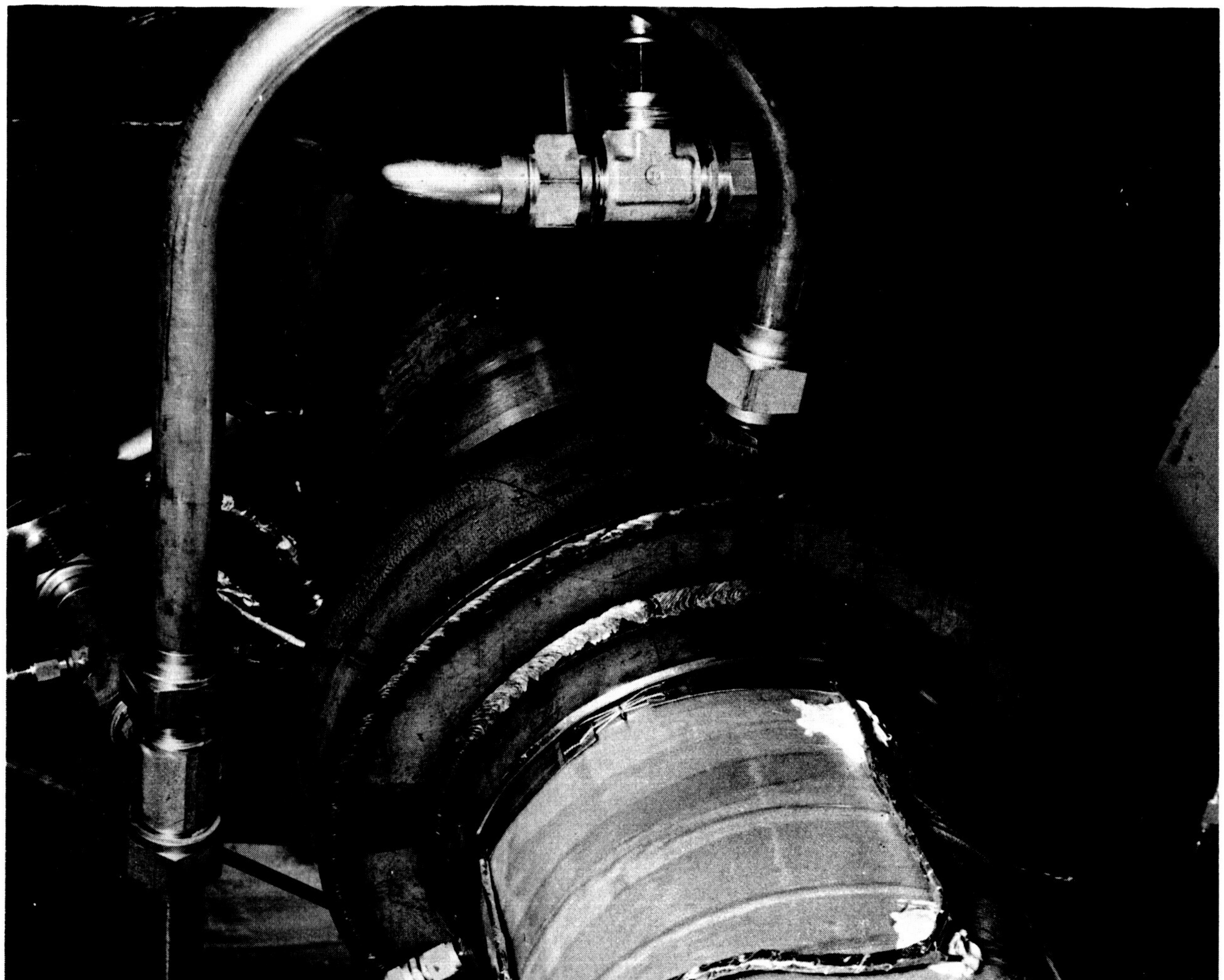


Figure VI-36. Engine Assembly S/N 2 Installed on Test Stand, Before Fire Test

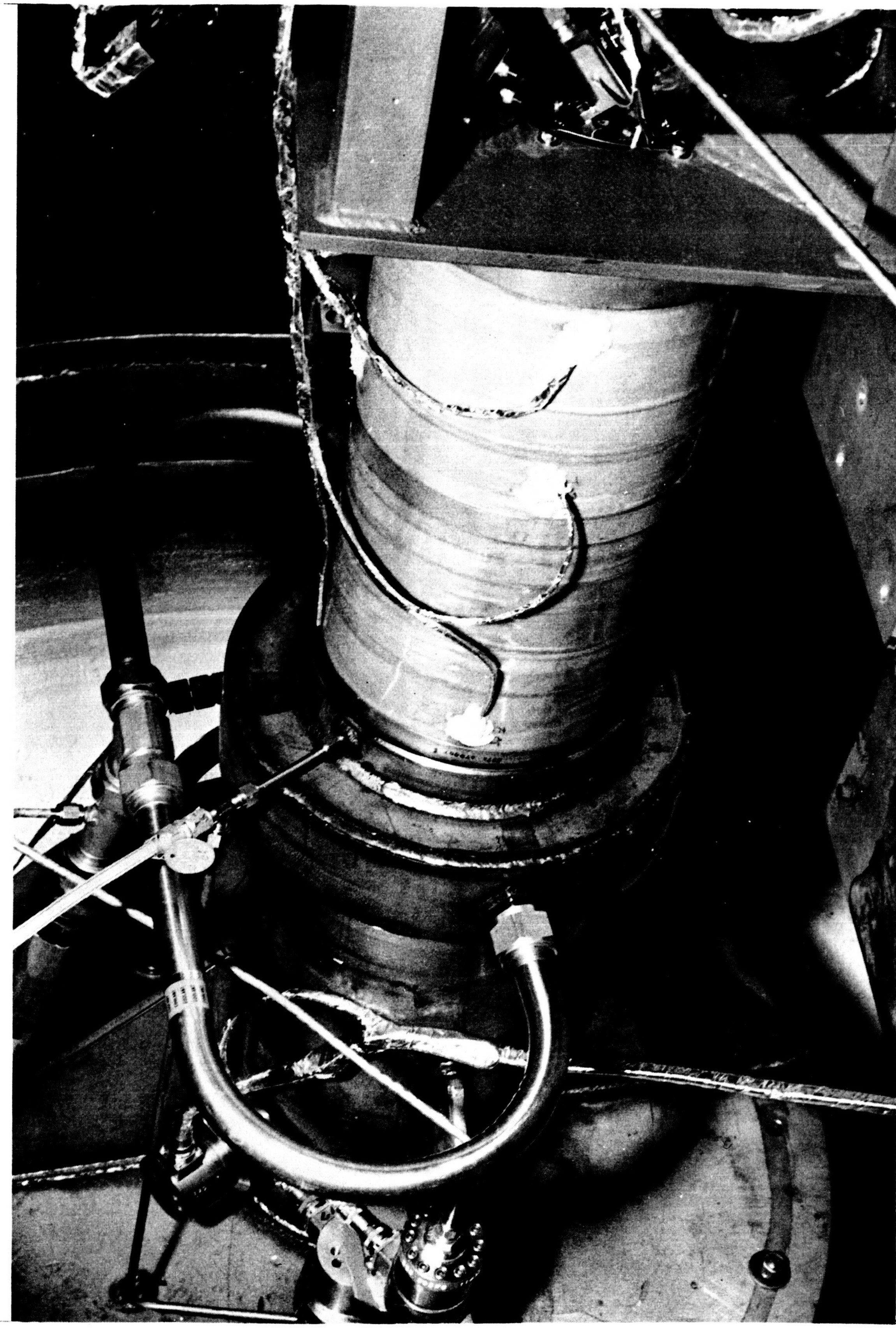


Figure VI-37. Engine Assembly S/N 2 Installed on Test Stand, Before Fire Test

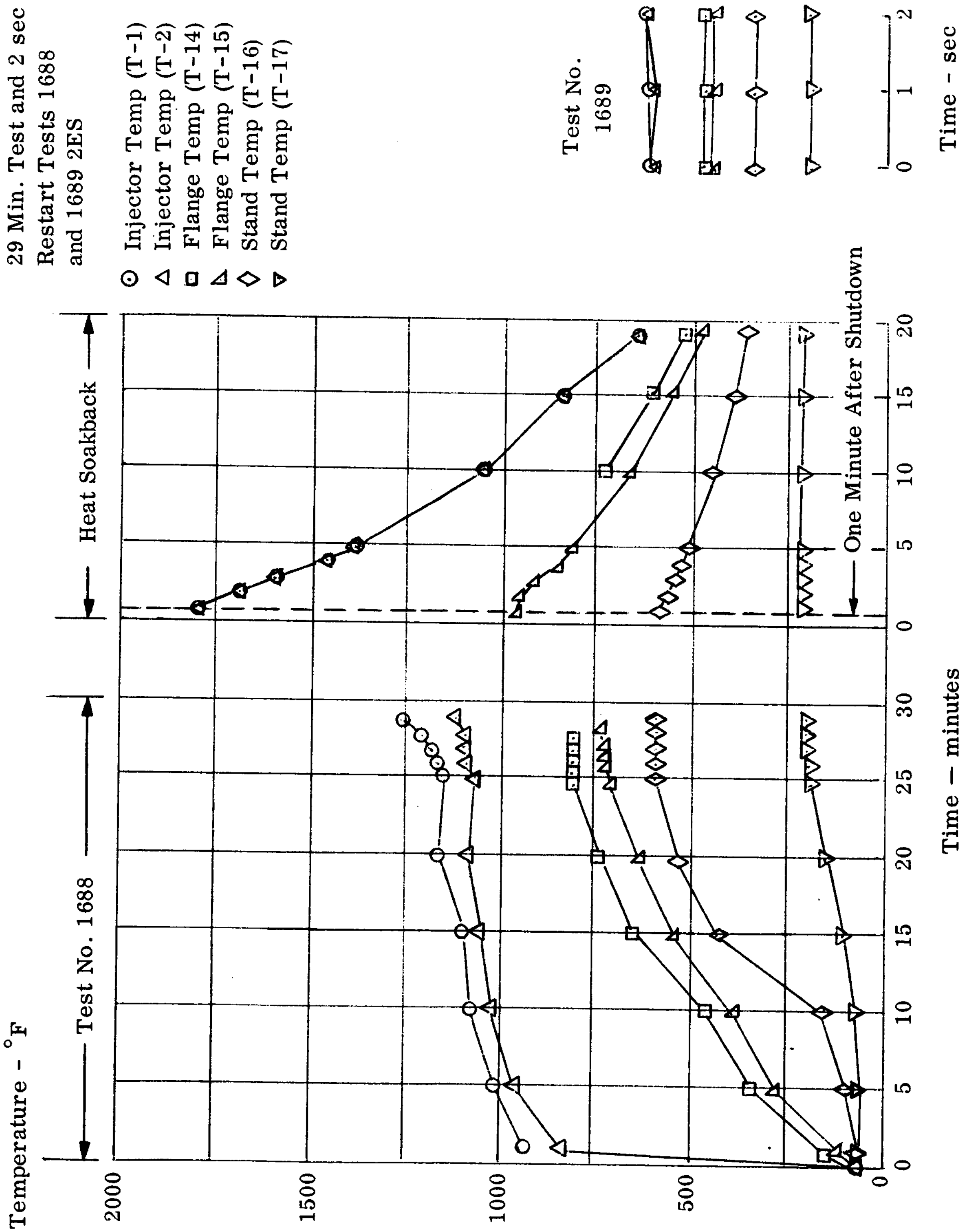


Figure VI-38. Injector Flange and Stand Temperature versus Time Engine S/N 2

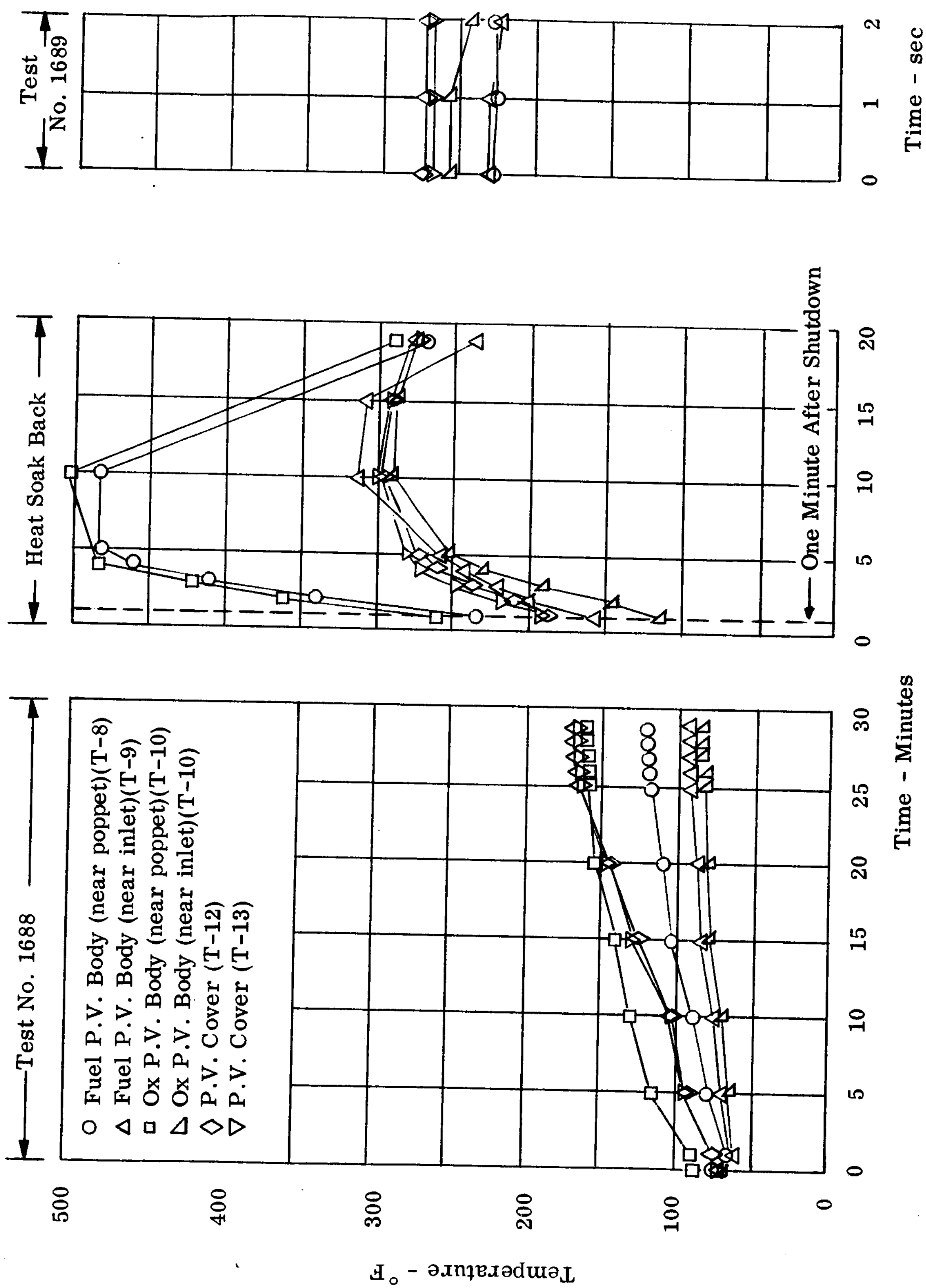


Figure VI-39. P.V. Temperature versus Time Engine S/N 2

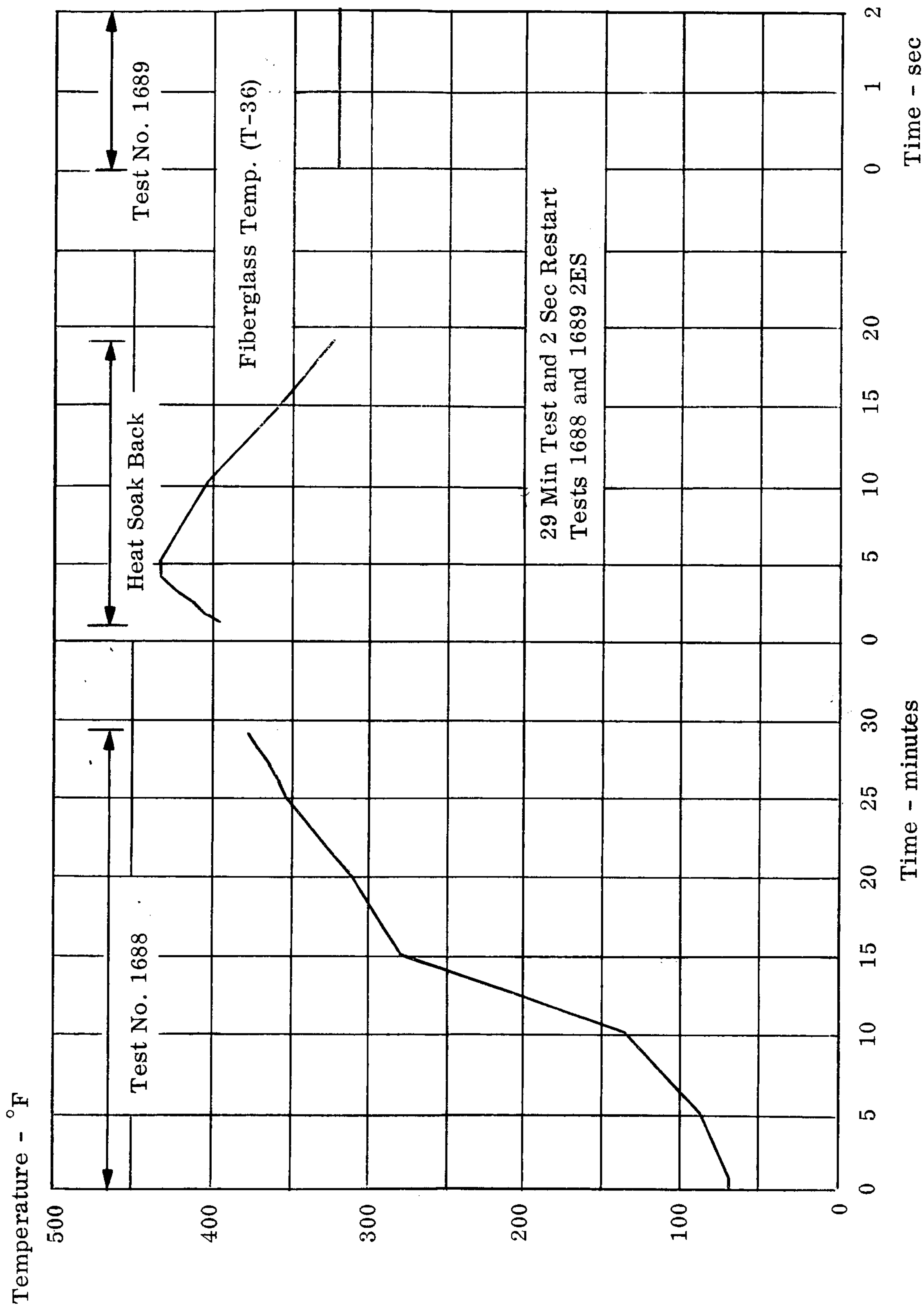


Figure VI-40. Fiberglass Temperature versus Time Engine 2

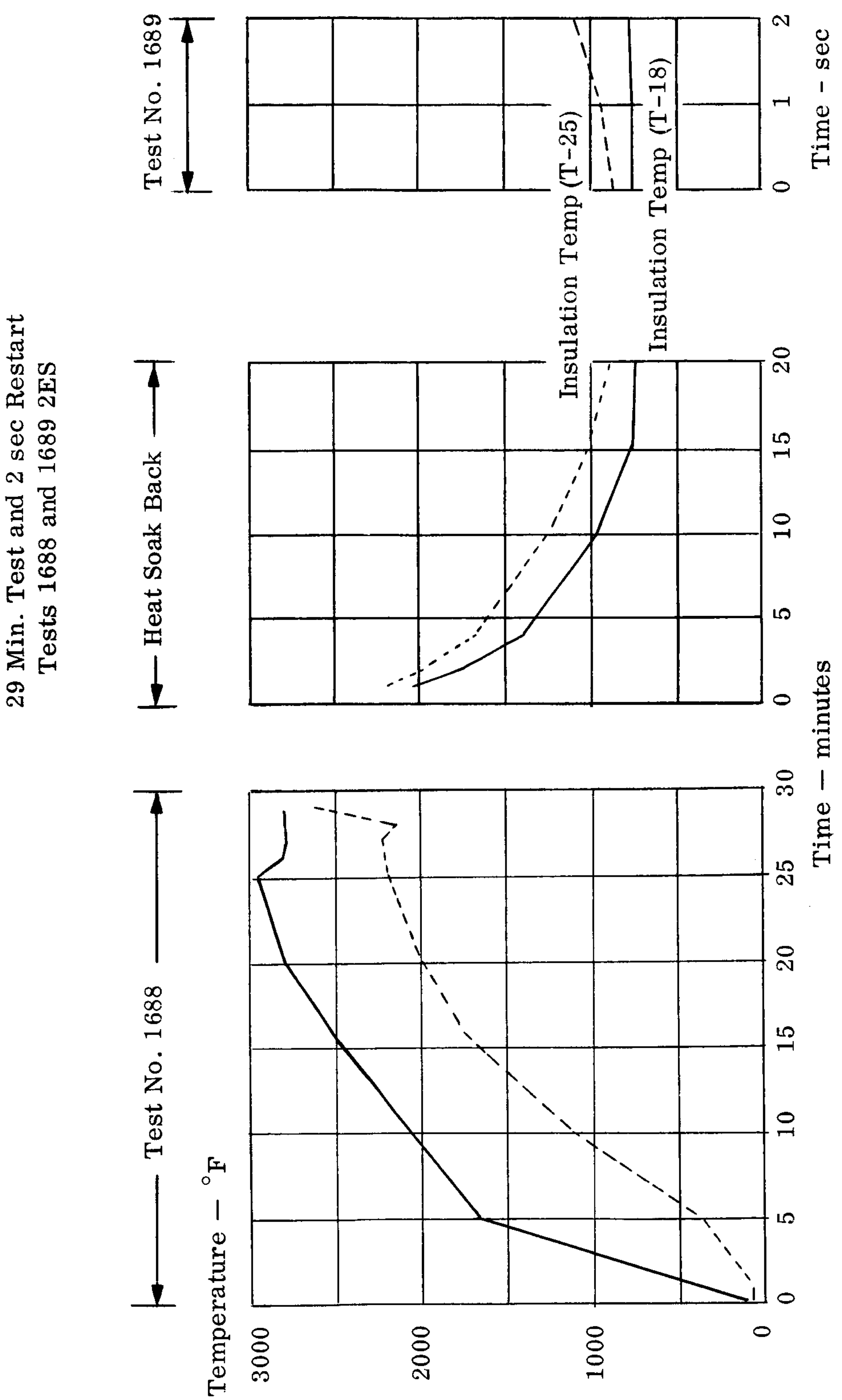


Figure VI-41. Insulation Temperature versus Time Engine S/N 2

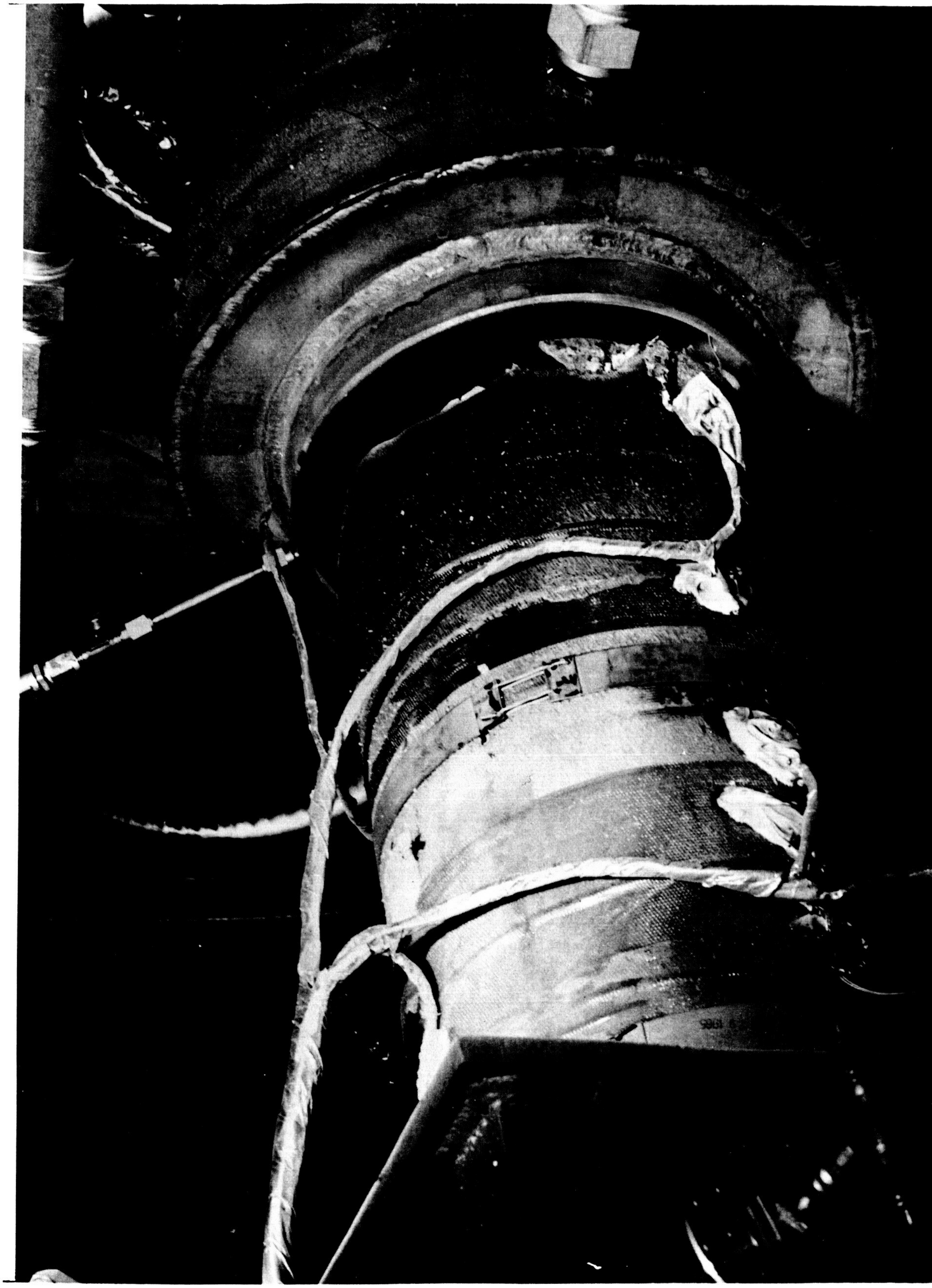


Figure VI-42. Engine Assembly S/N 2 After Fire Test

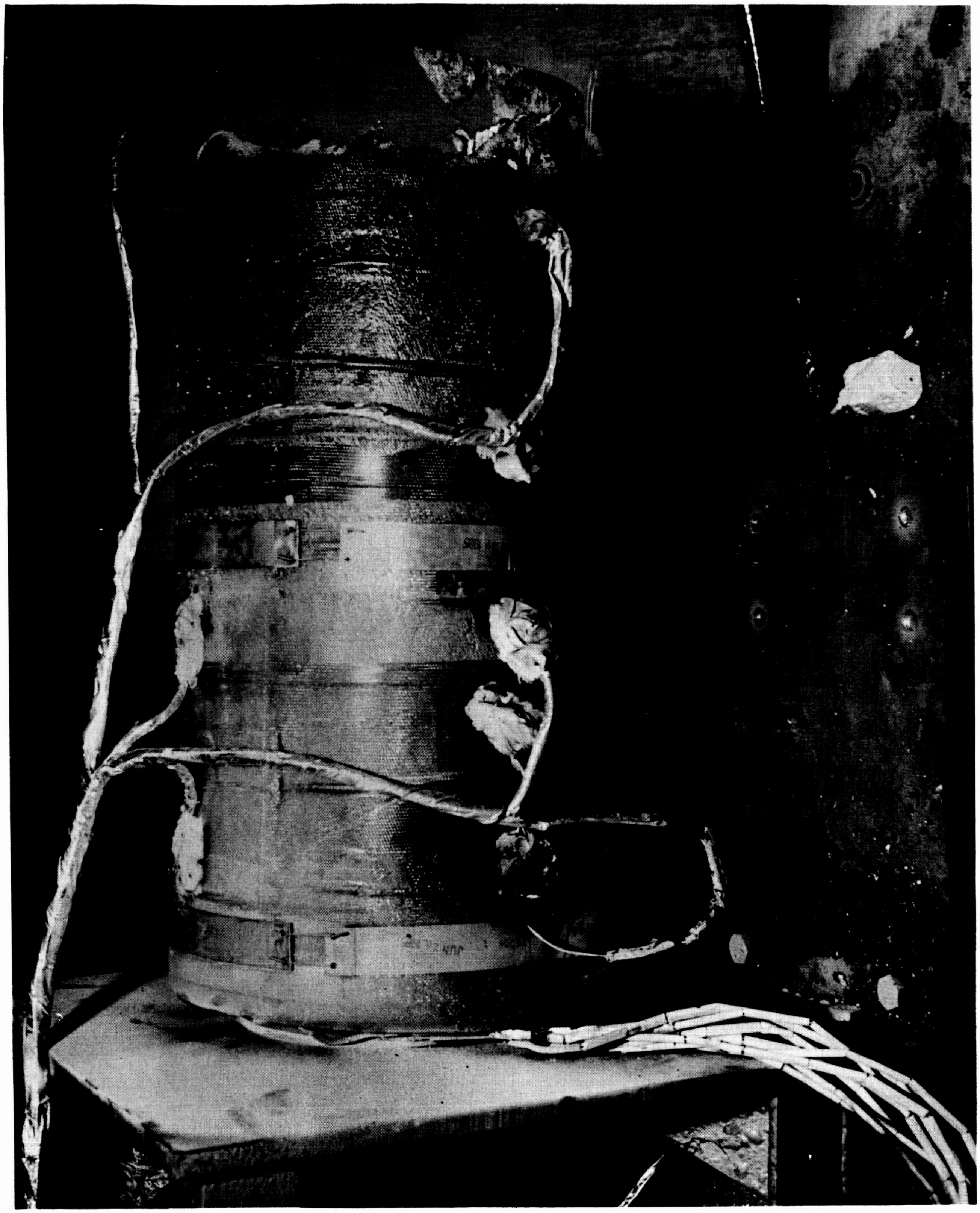


Figure VI-43. Engine Assembly S/N 2 After Fire Test

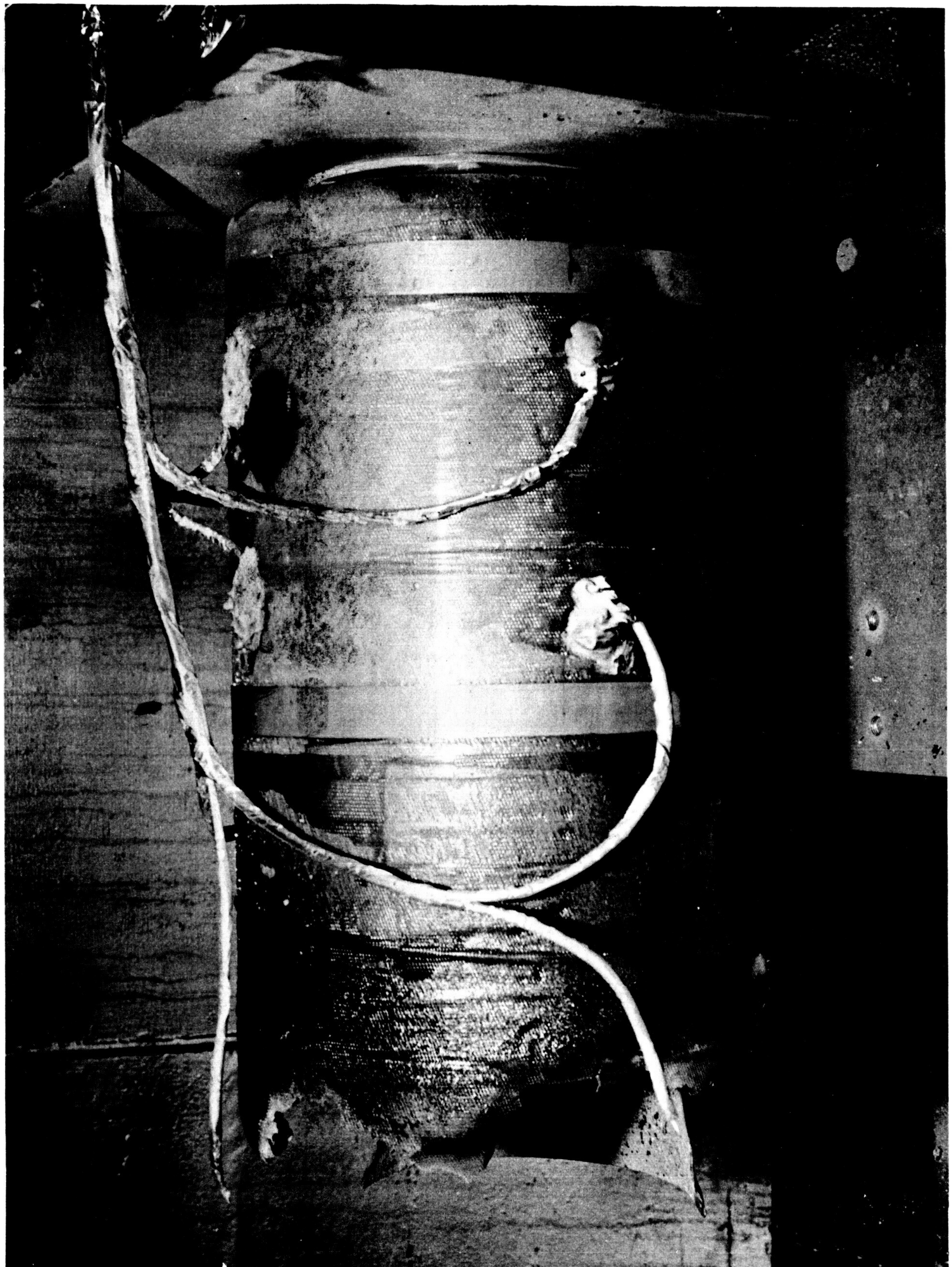


Figure VI-44. Engine Assembly S/N 2 After Fire Test

Figure VI-45. Engine Assembly S/N 2 After Fire Test

Figure VI-46. Engine Assembly S/N 2 After Fire Test (30 Minutes and 3 Seconds Accumulated Time)

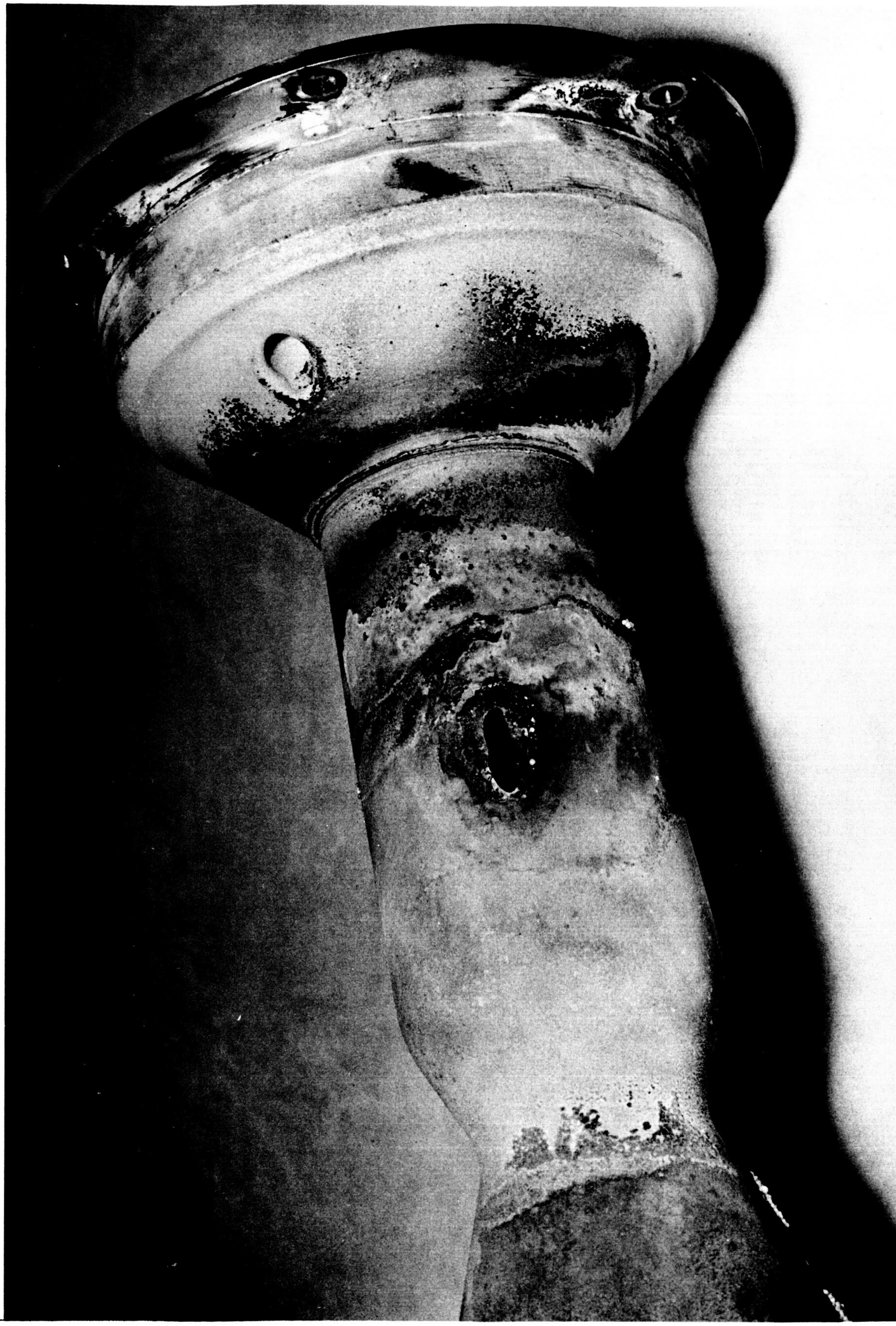


Figure VI-47. Chamber Burnout Region - Engine Assembly S/N 2 After Fire Test

Figure VI-48. Chamber From Engine Assembly S/N 2 After Fire Test

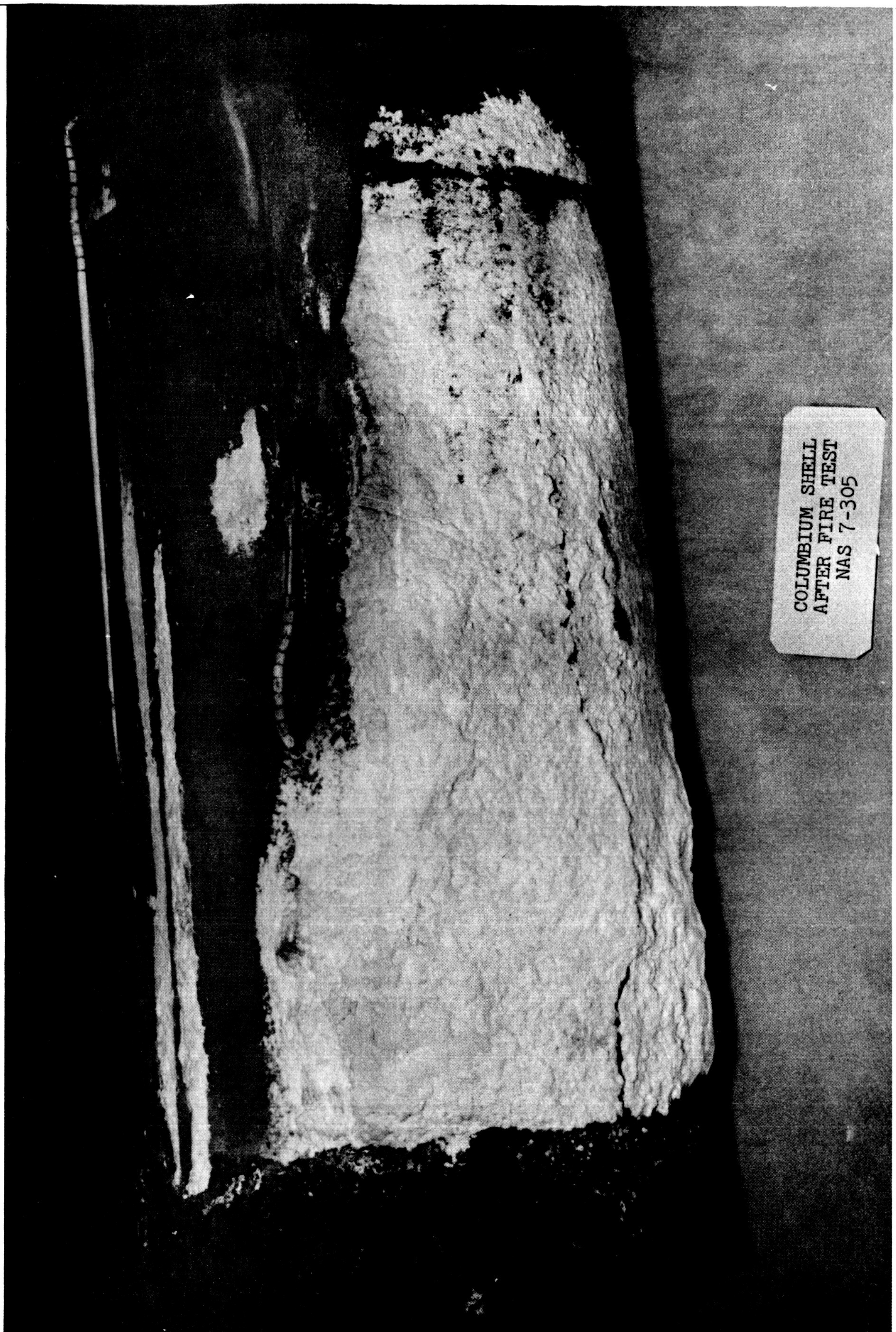


Figure VI-49. Columbium Shell From Engine Assembly S/N 2 After Fire Test

Figure VI-50. Dyna-Quartz Insulation From Engine Assembly S/N 2 After Fire Test

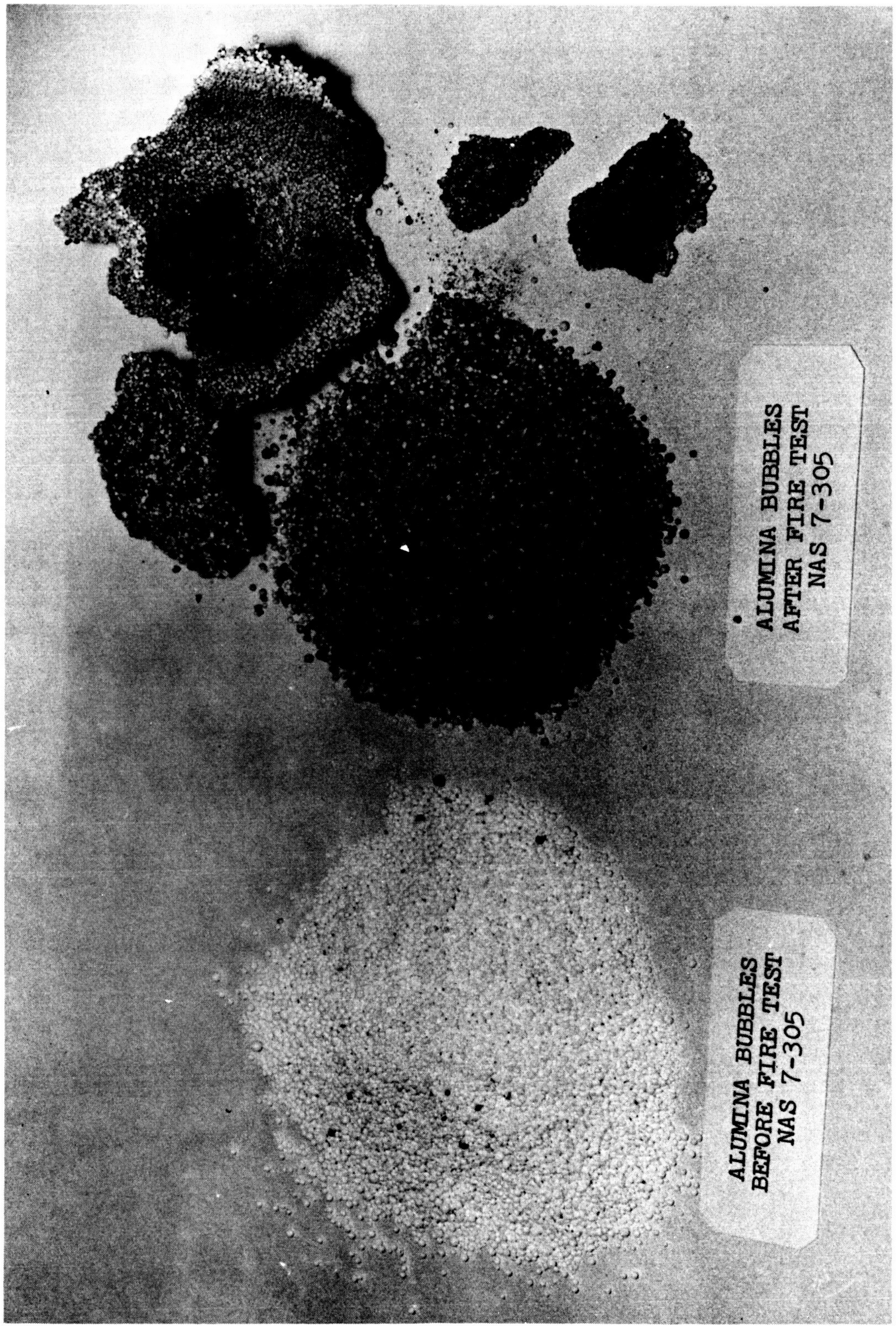


Figure VI-51. Alumina Bubbles - Comparison Before and After Fire Test Engine Assembly S/N 2

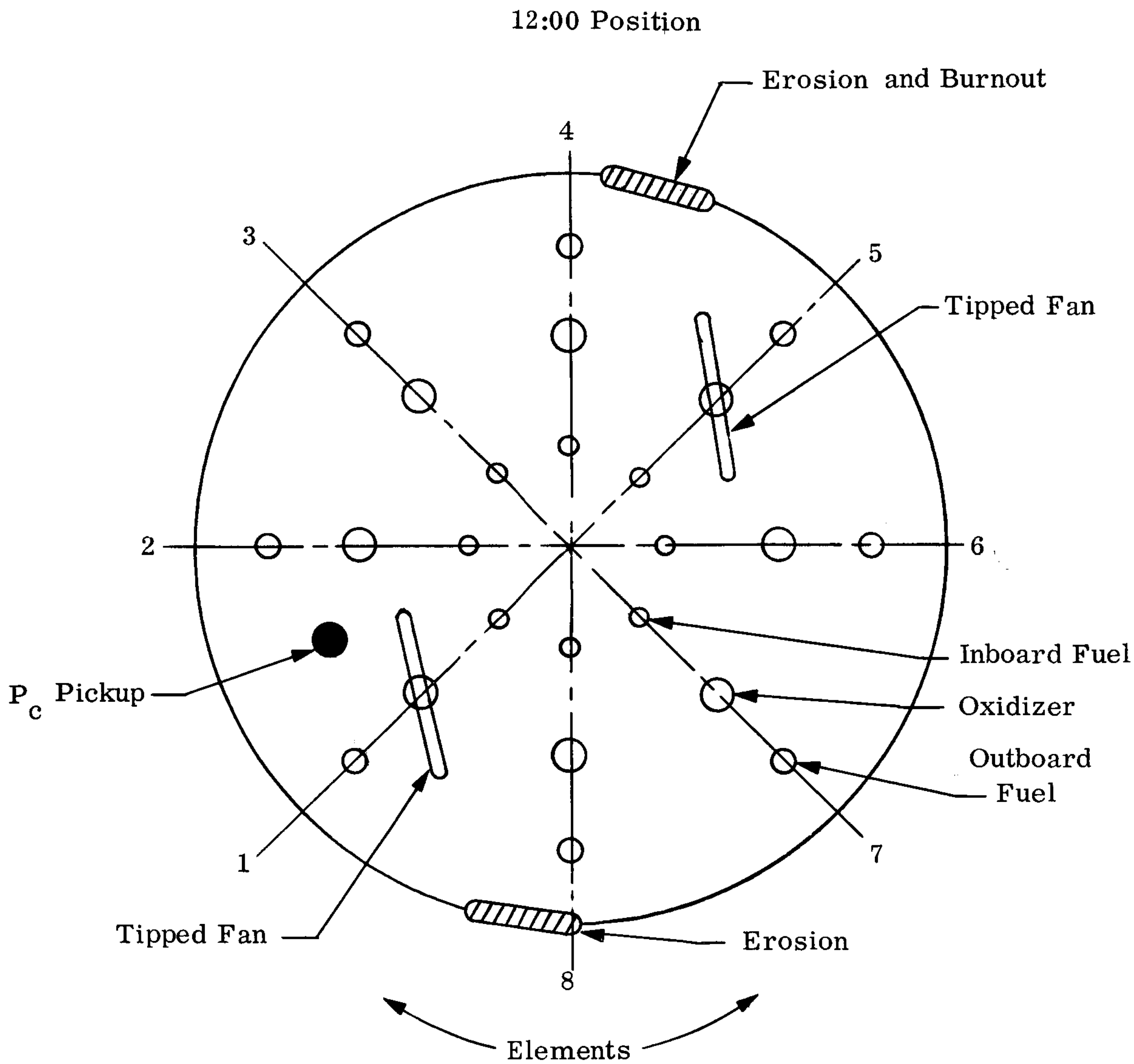


Figure VI-52. Injector S/N 2-C Water Flow Impingement After Fire Test of Engine Assembly S/N 2

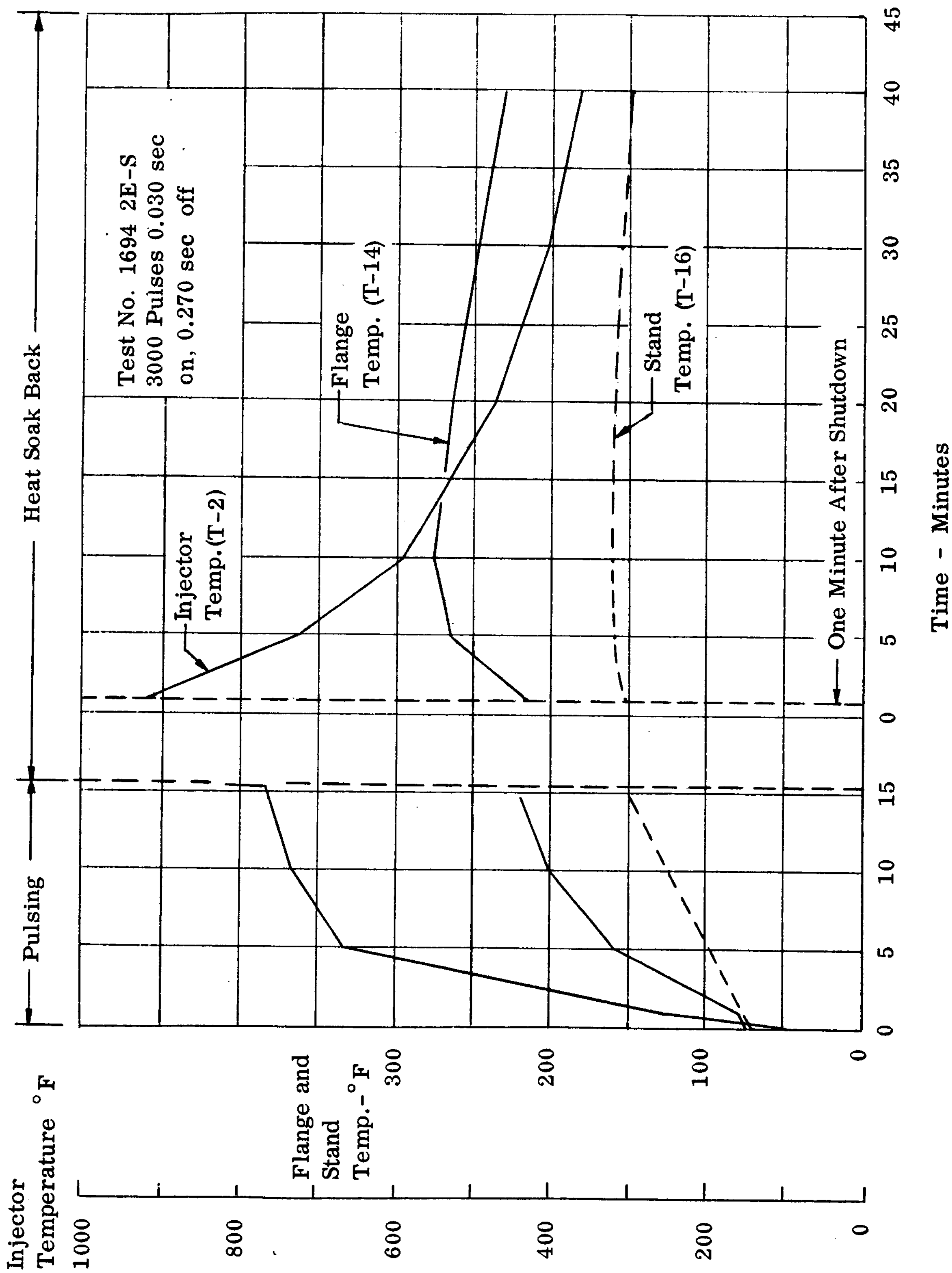


Figure VI-53. Injector Temperature Versus Time - Engine S/N 1

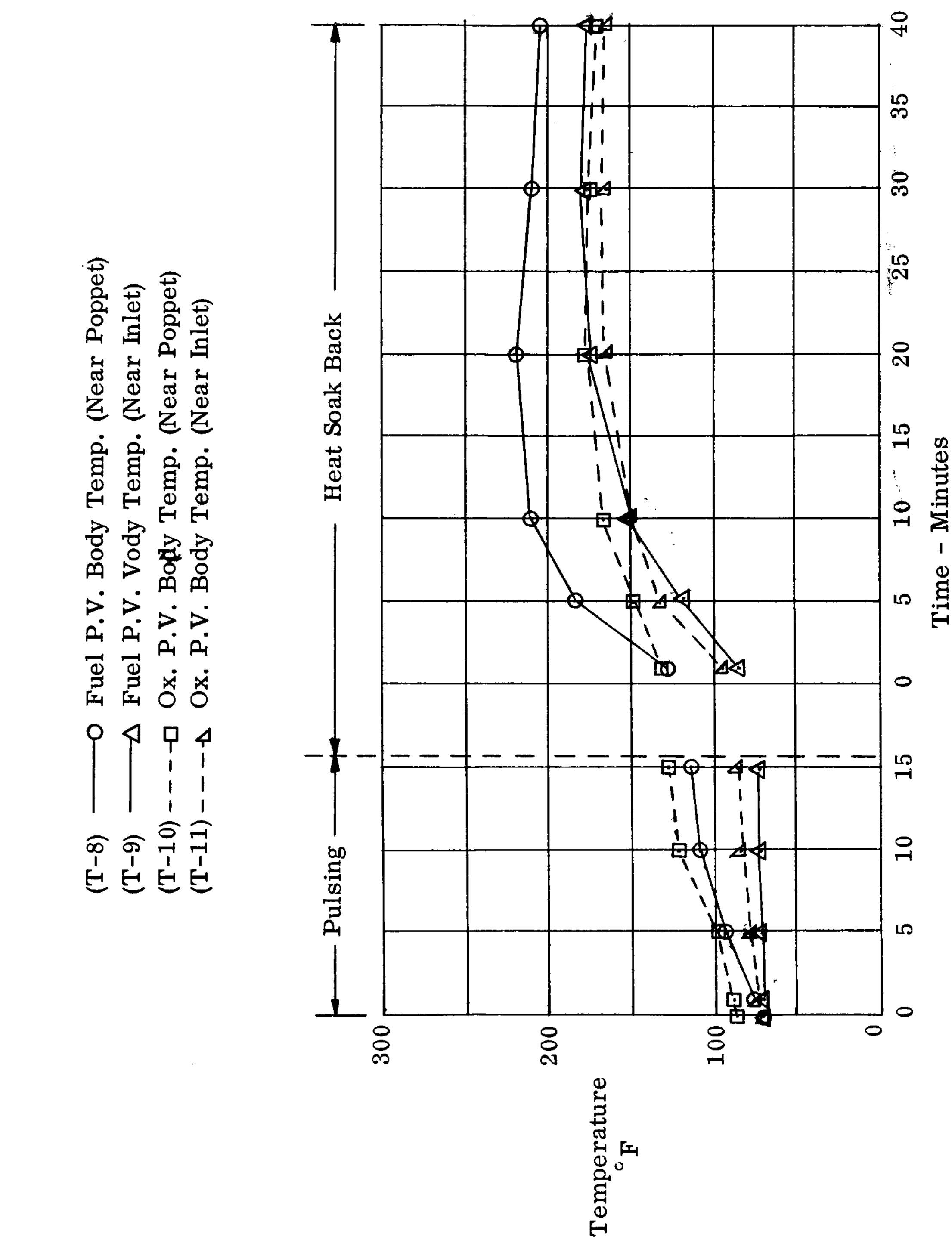


Figure VI-54. P.V. Body Temperature Versus Time-Engine S/N 1

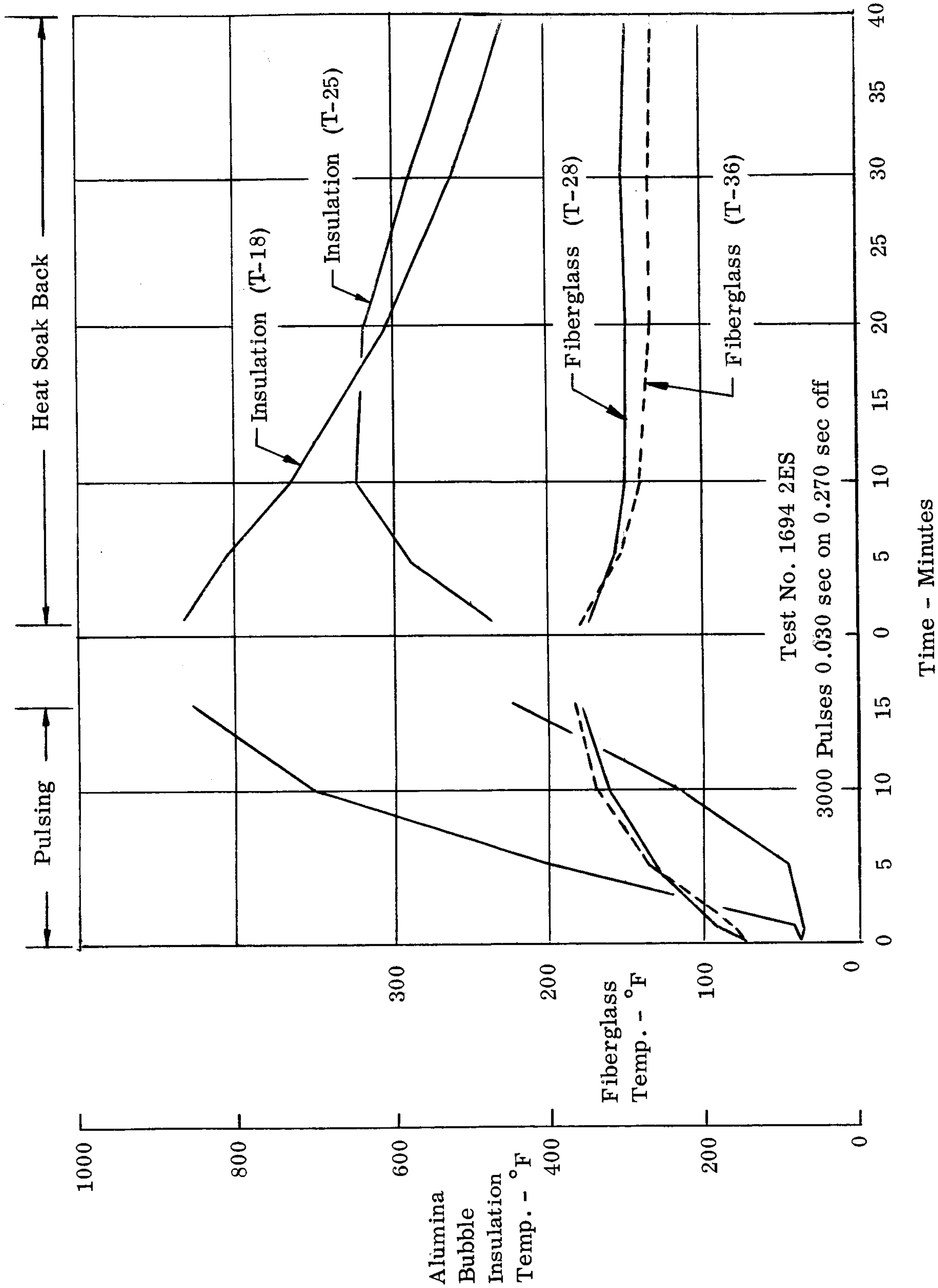


Figure VI-55. Insulation and Fiberglass Temperature versus Time Engine S/N 1

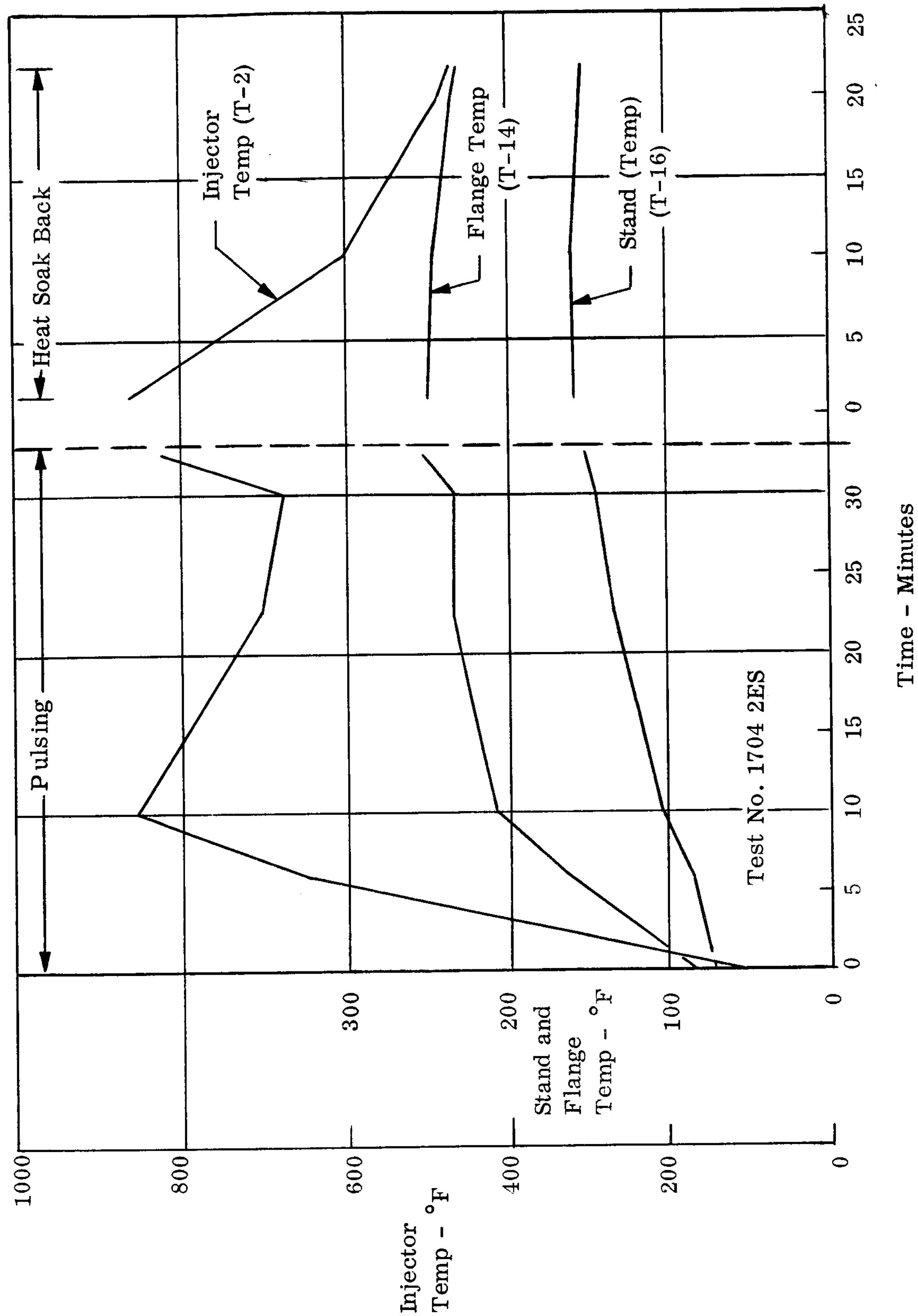


Figure VI-56. Injector, Flange, and Stand Temperature versus Time - Engine S/N 1 - Apollo Command Module Duty Cycle

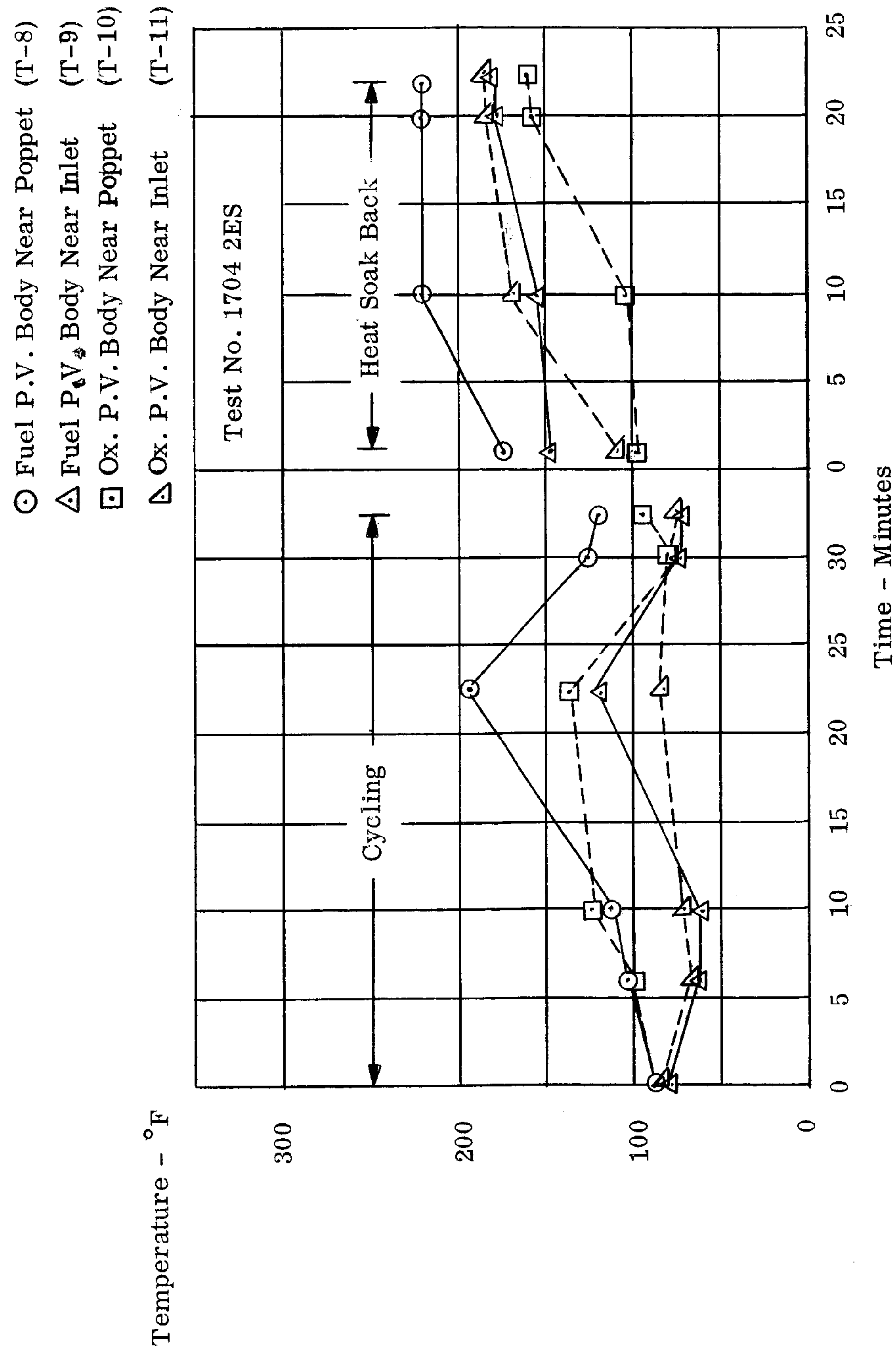


Figure VI-57. Propellant Valve Temperature Versus Time - Engine S/N 1

Apollo Command Module Duty Cycle

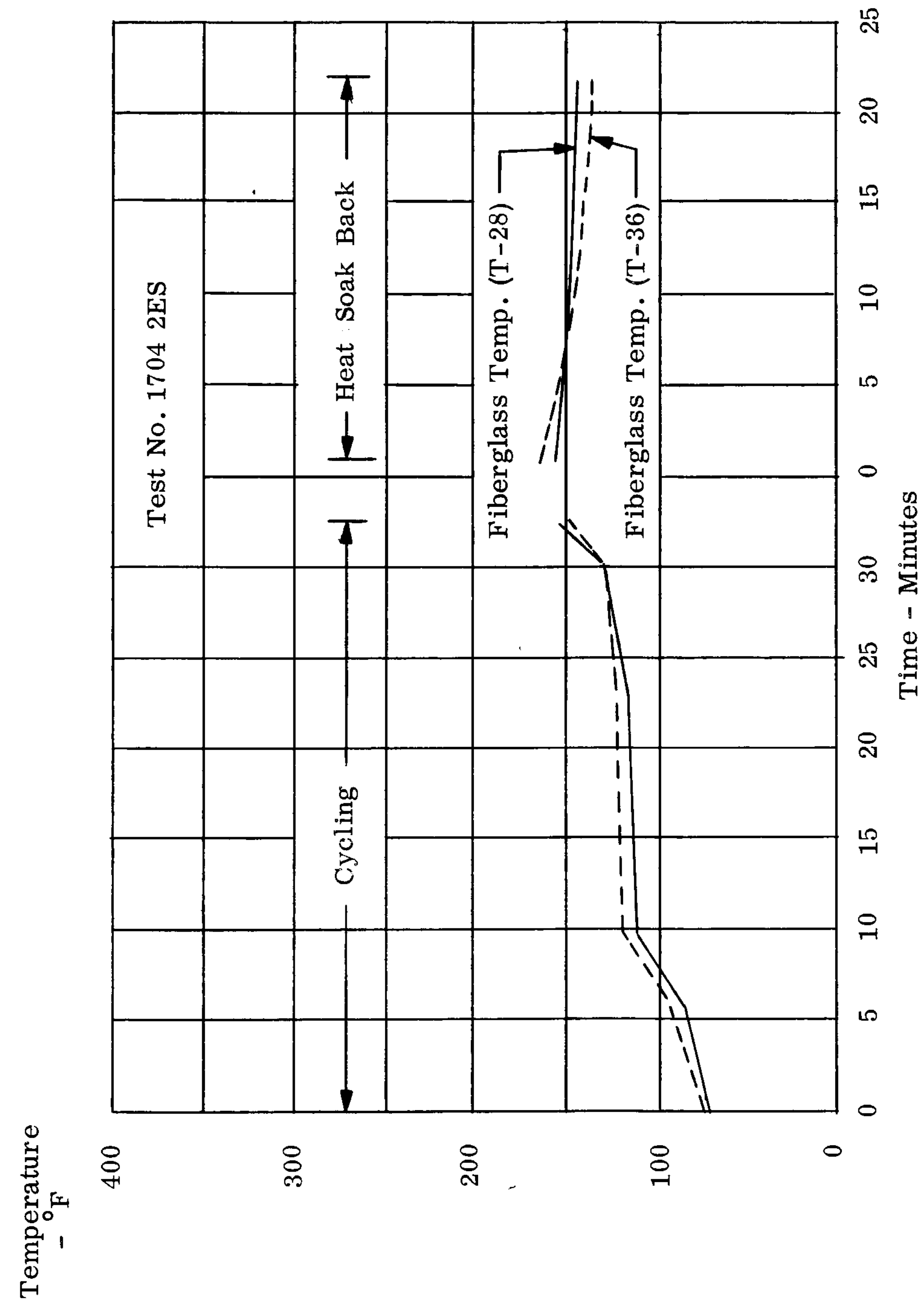


Figure VI-58. Fiberglass Temperature Versus Time - Engine S/N 1 - Apollo Command Module Duty Cycle

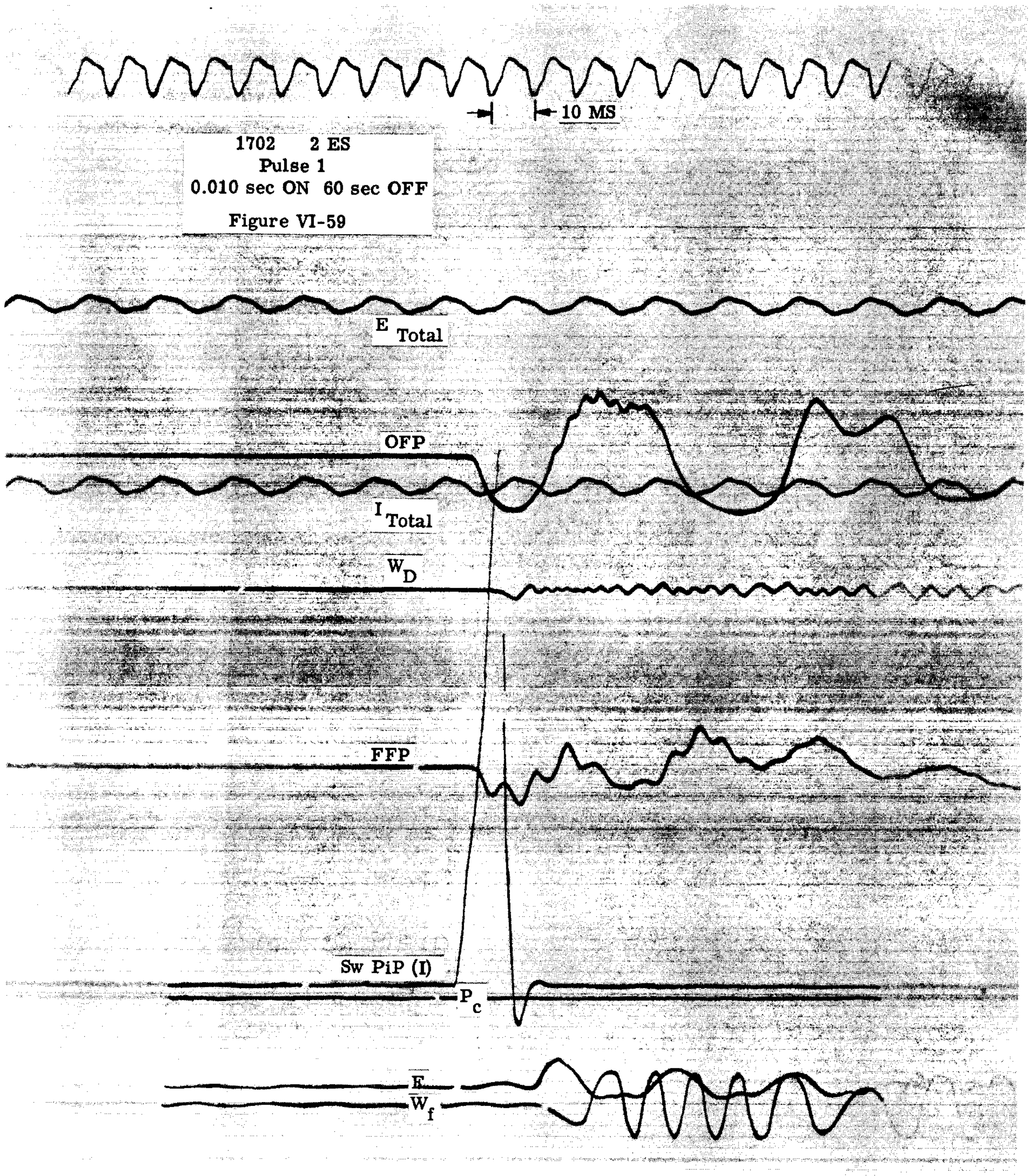


Figure VI-59. Oscillograph Trace - Pulse 1 (0.010 Sec On - 60 Sec Off)

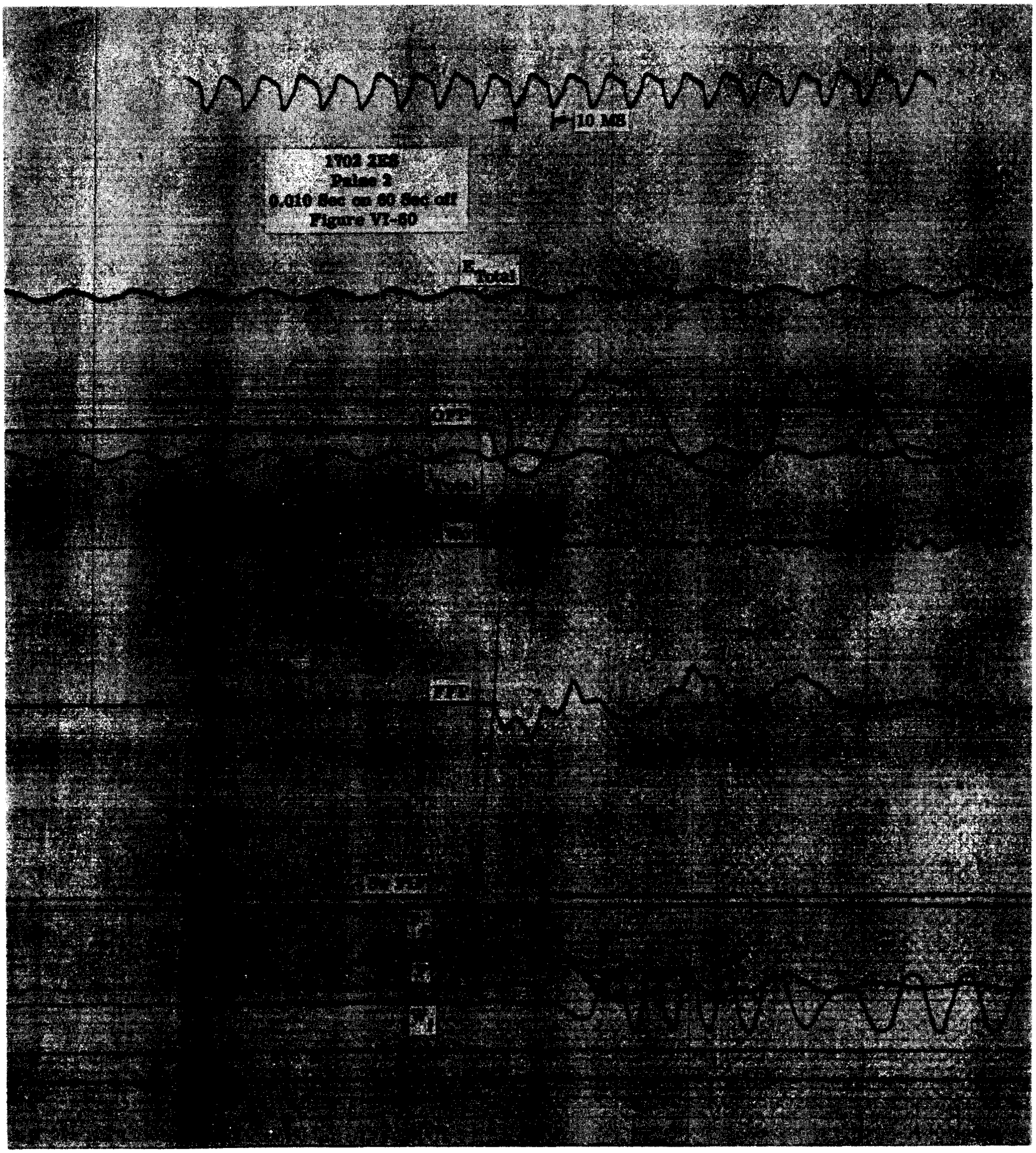


Figure VI-60. Oscillograph Trace - Pulse 2 (0.010 Sec On - 60 Sec Off)

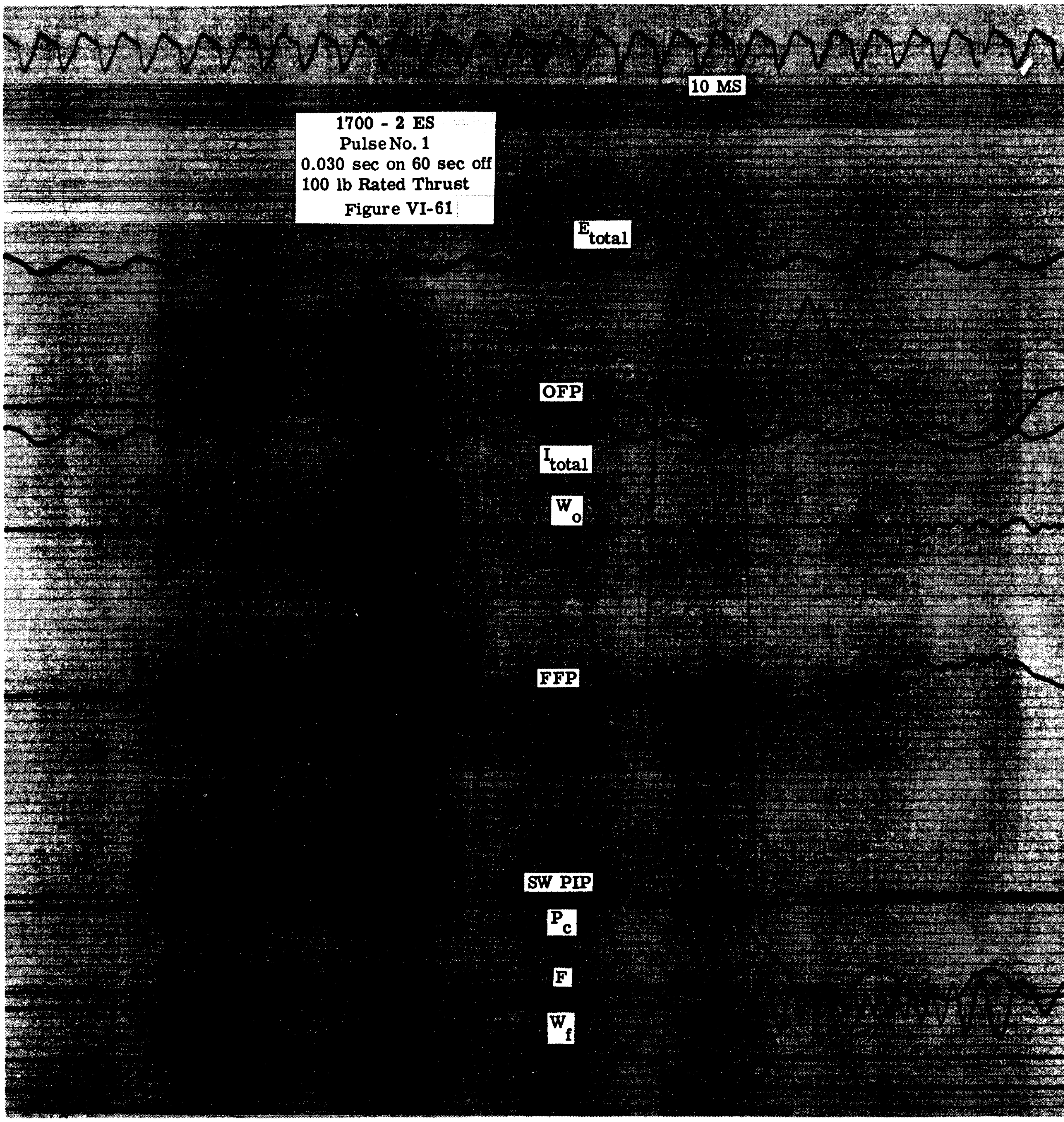


Figure VI-61. Oscillograph Trace - Pulse 1 (0.030 Sec On - 60 Sec Off)

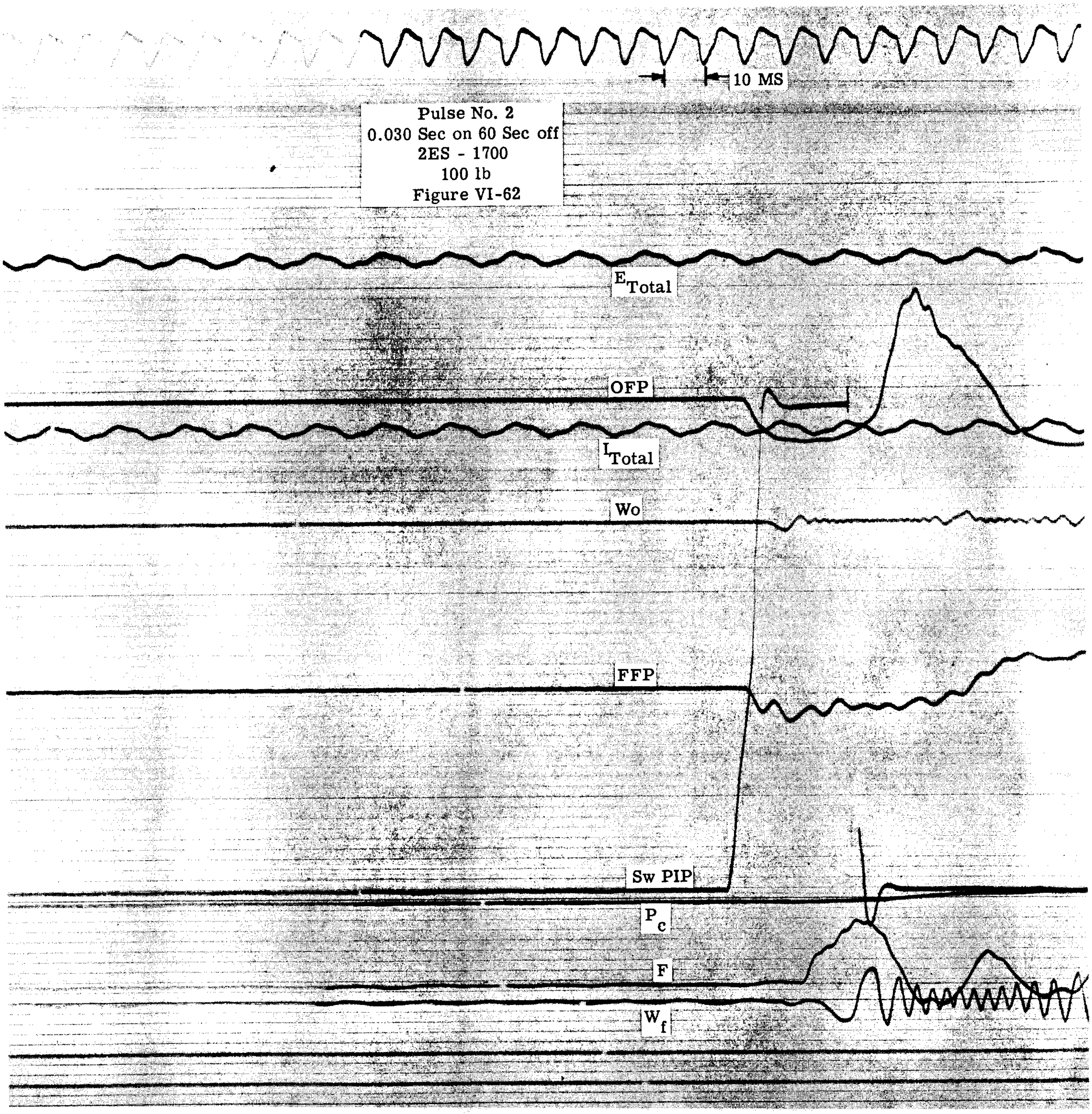


Figure VI-62. Oscillograph Trace - Pulse 2 (0.030 Sec On - 60 Sec Off)

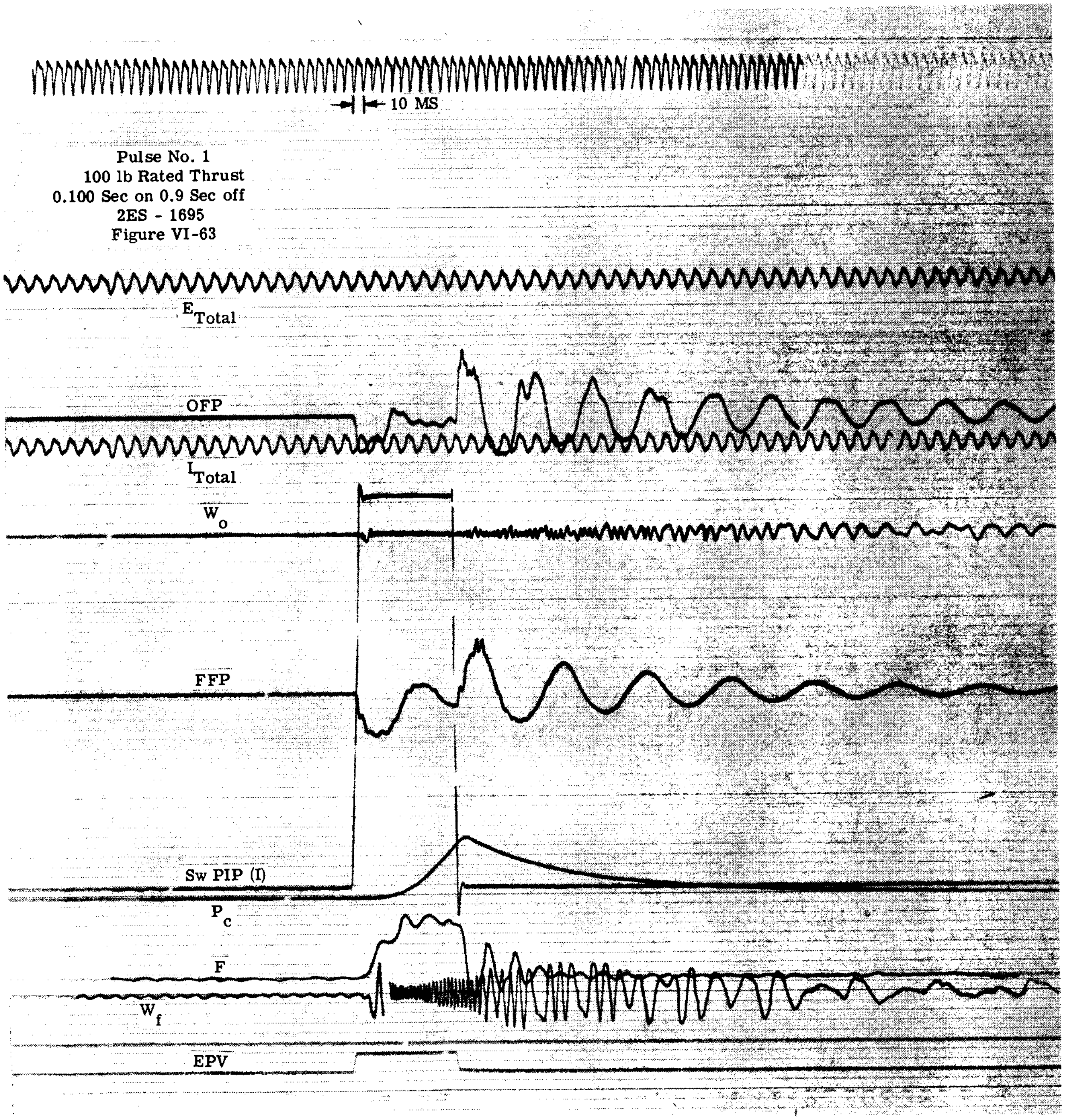


Figure VI-63. Oscillograph Trace - Pulse 1 (0.100 Sec On - 0.9 Sec Off)

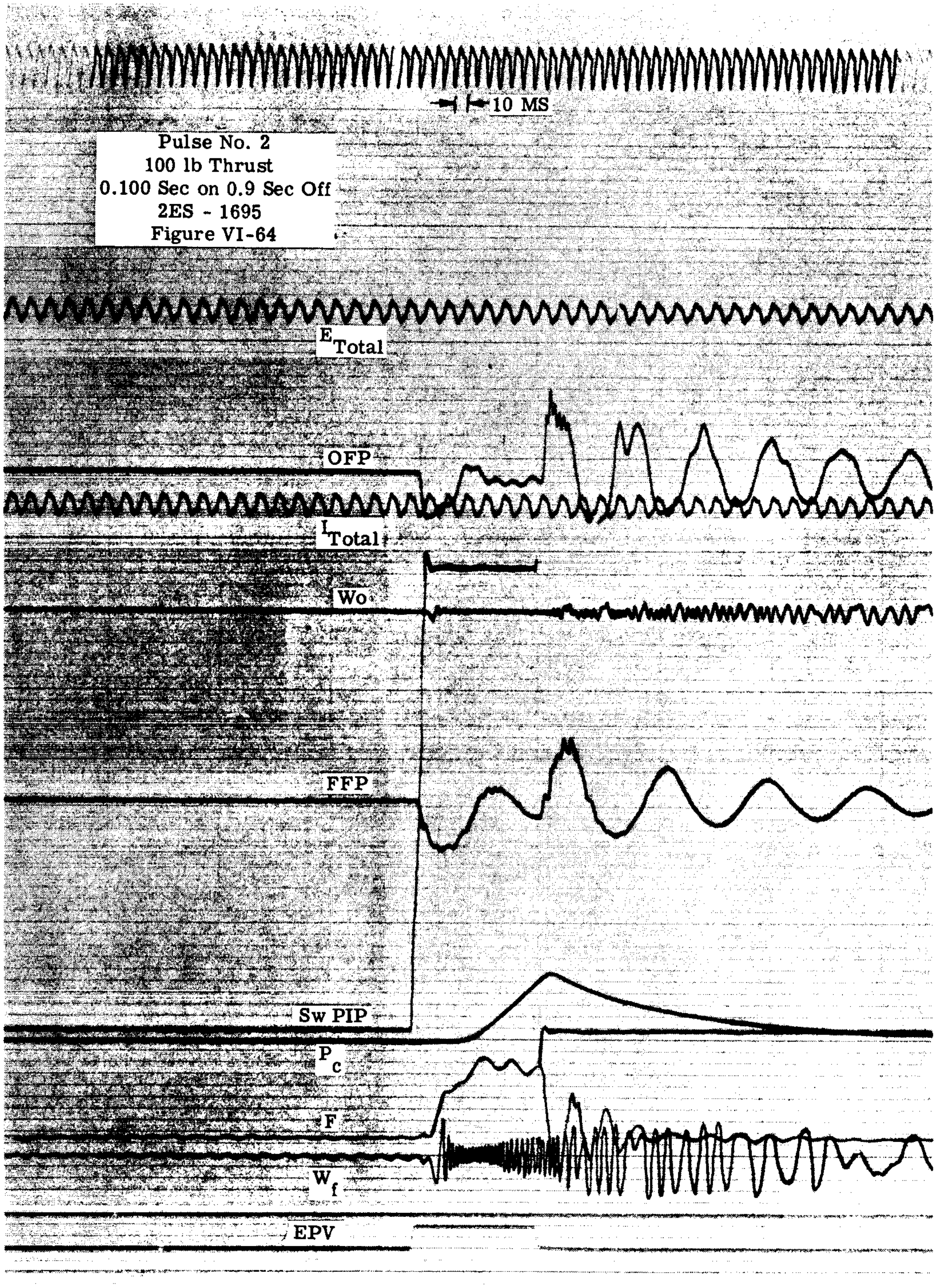


Figure VI-64. Oscillograph Trace - Pulse 2 (0.100 Sec On - 0.9 Sec Off)

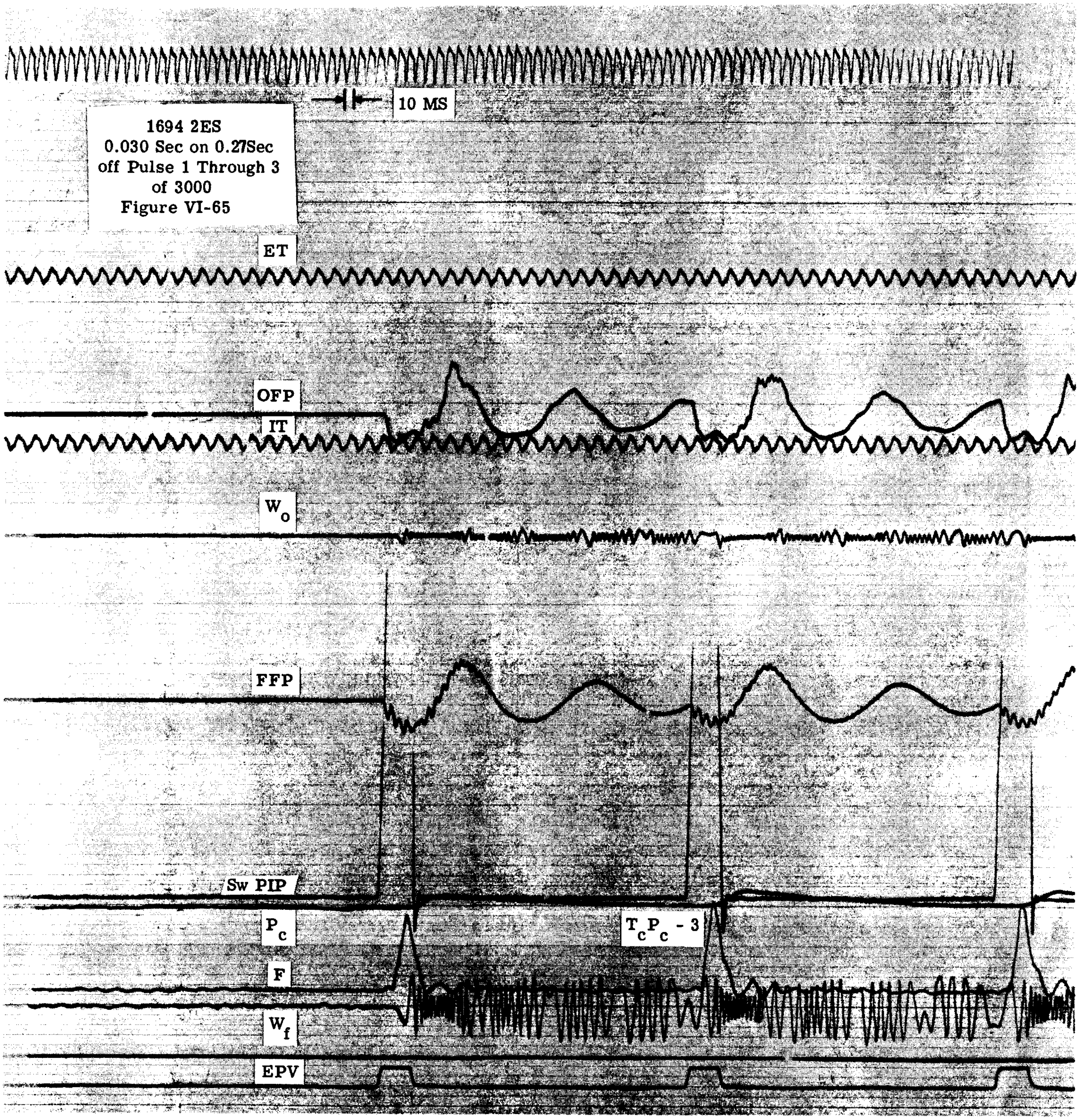


Figure VI-65. Oscillograph Trace - Pulses 1 - 3 (0.030 Sec On - 0.270 Sec Off)

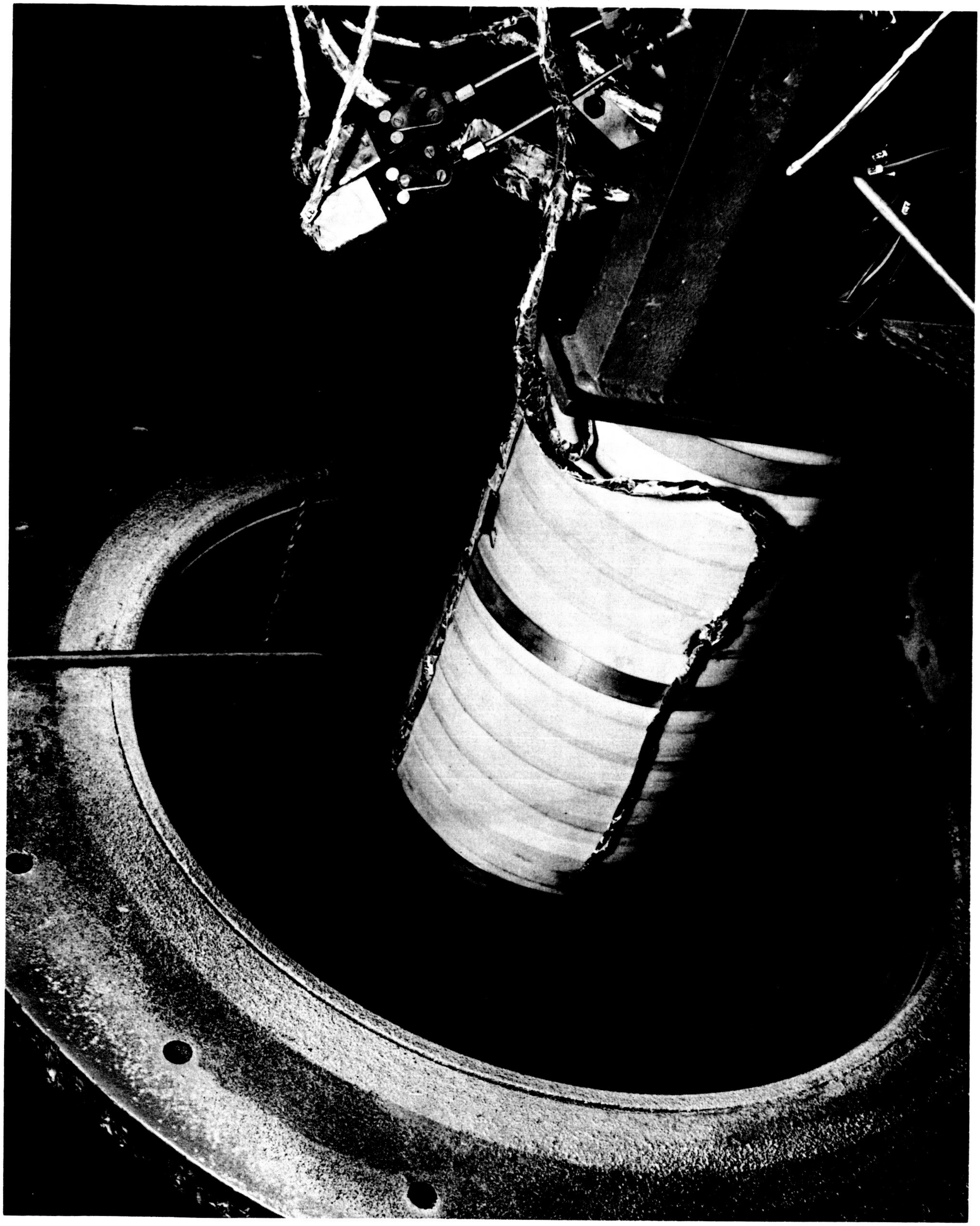


Figure VI-66. Prototype Engine S/N 1 Installed in Altitude Facility

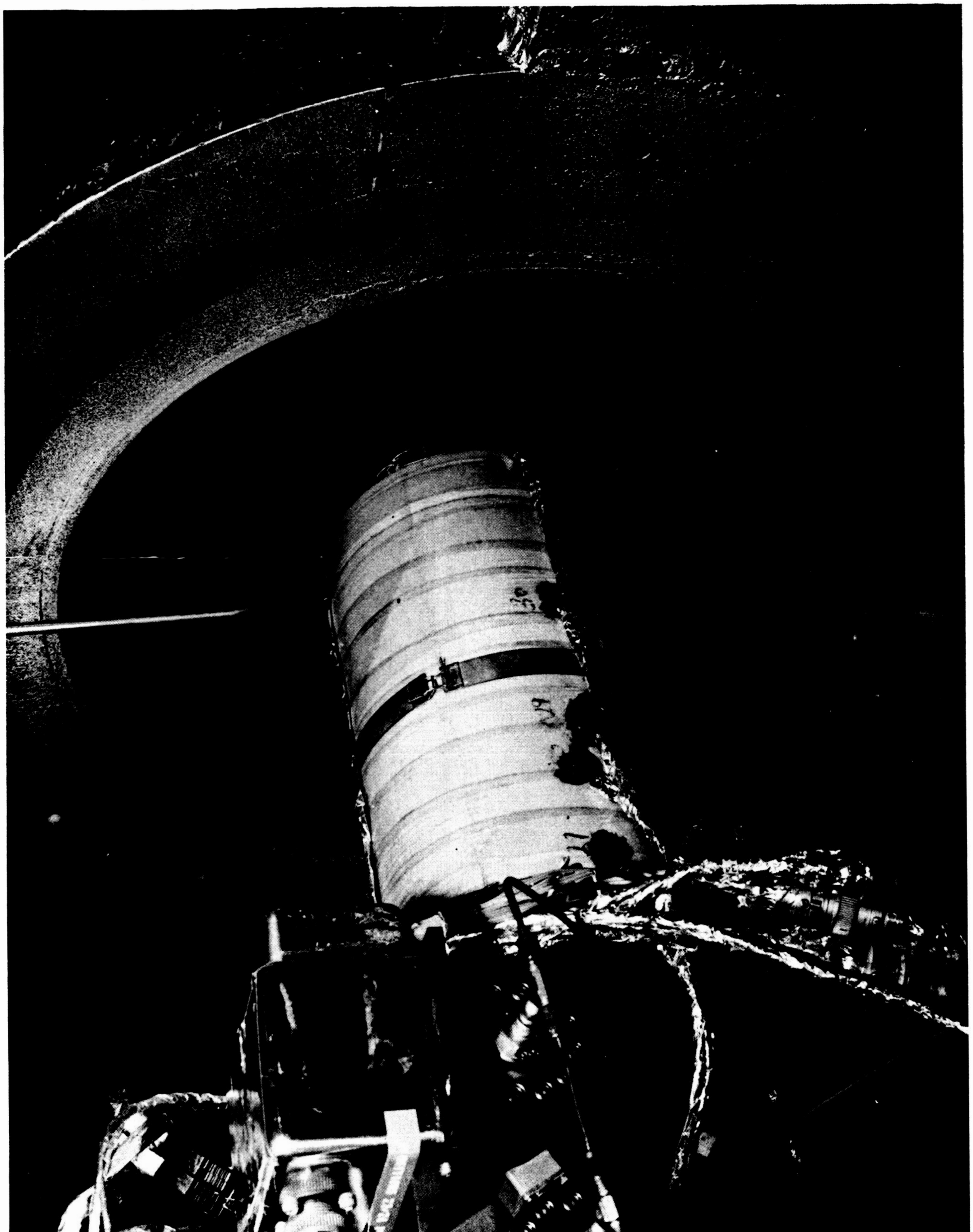


Figure VI-67. Prototype Engine S/N 1 Installed in Altitude Facility

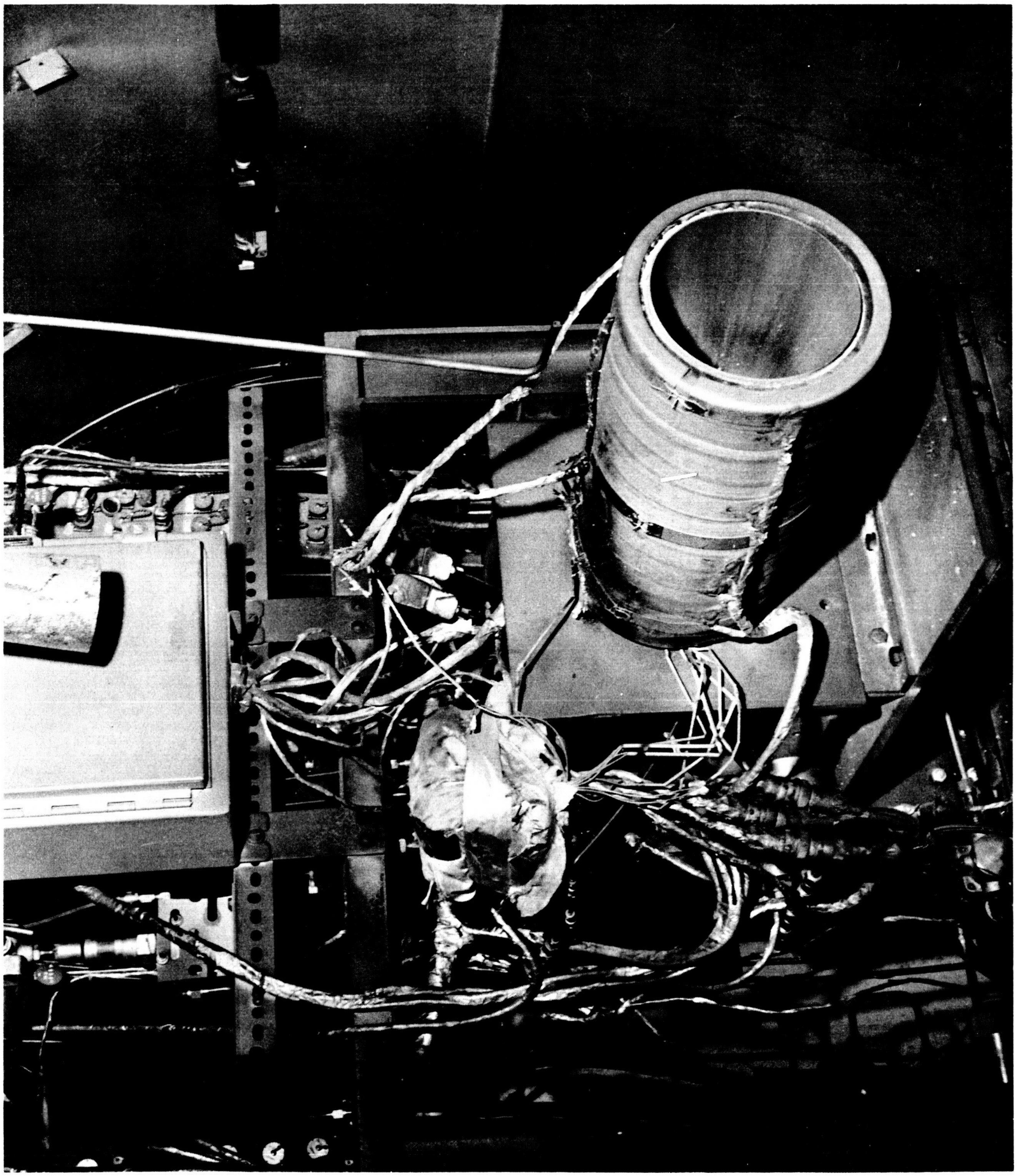


Figure VI-68. Engine S/N 1 After Test

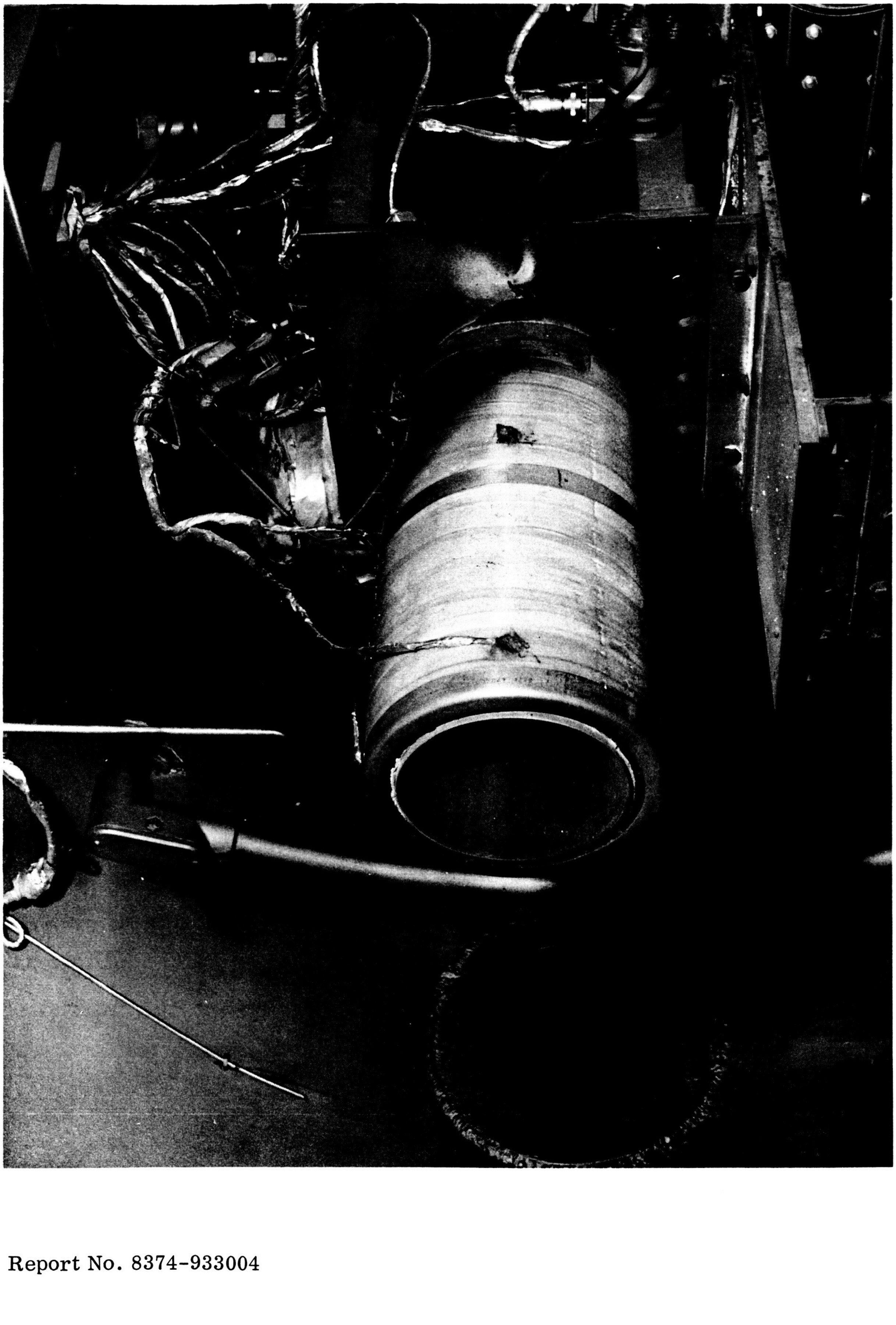


Figure VI-69. Engine S/N 1 After Test

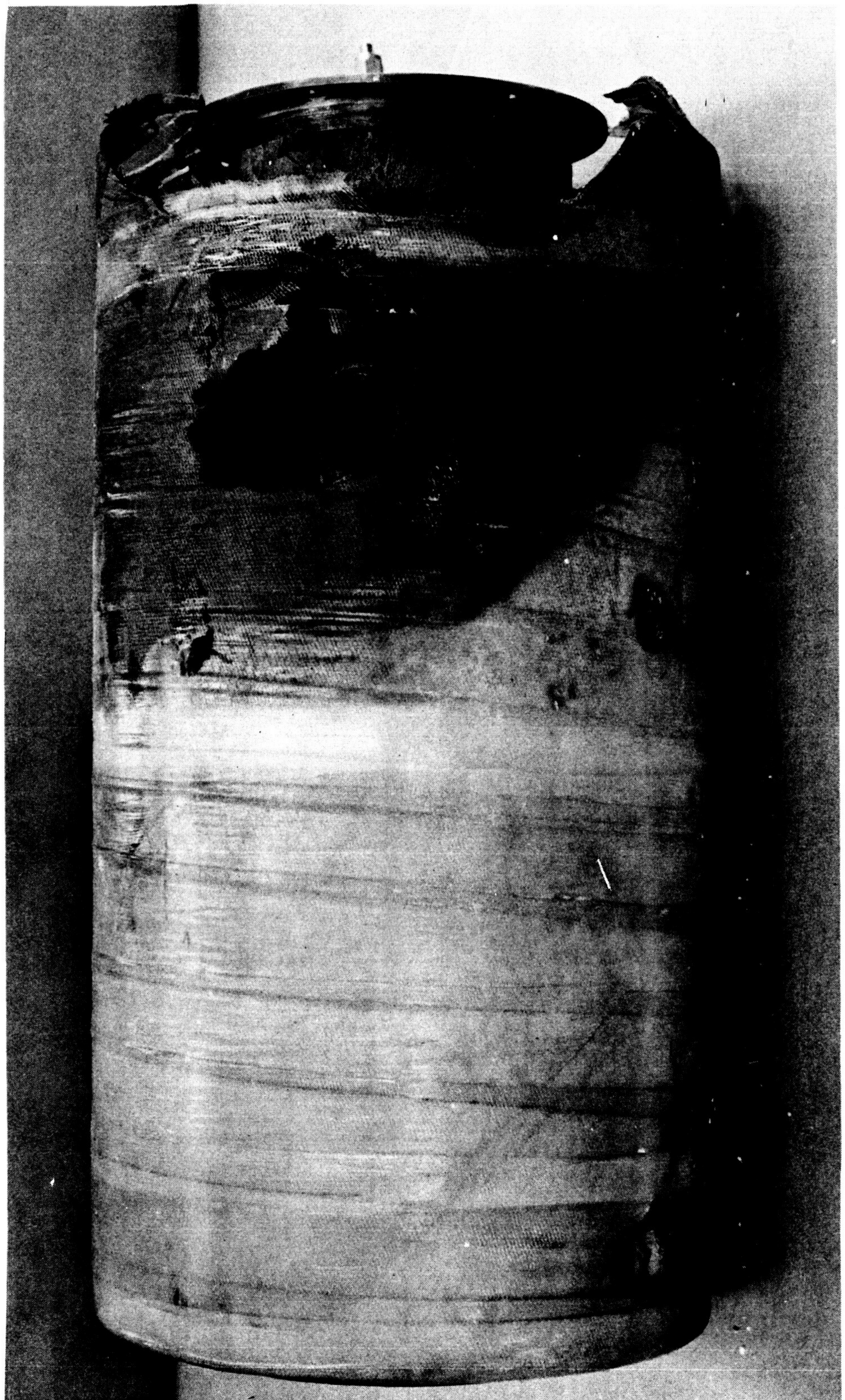


Figure VI-70. Engine S/N 1 After Test

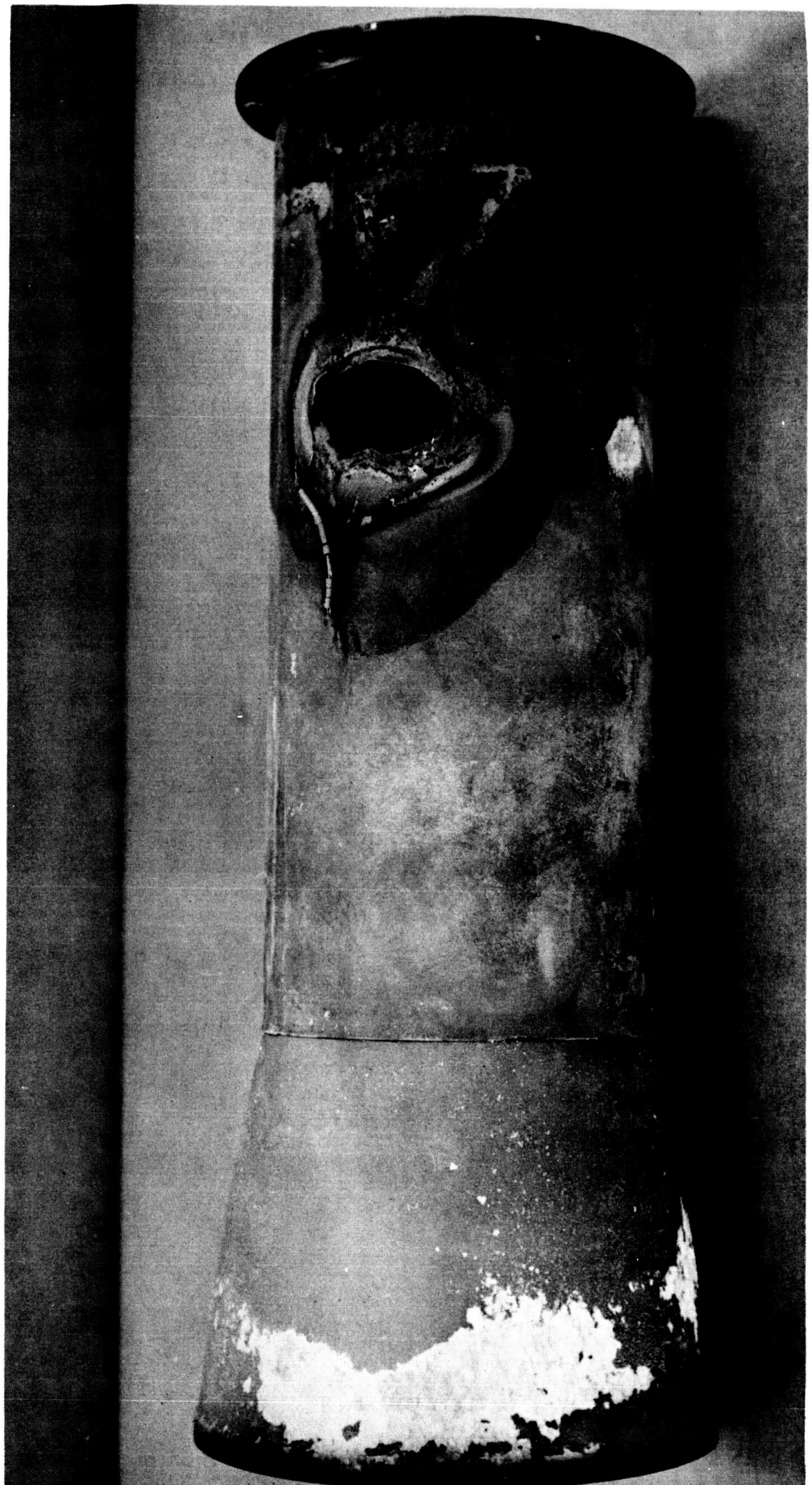


Figure VI-71. Engine S/N 1 After Test Dyna-Quartz Removed

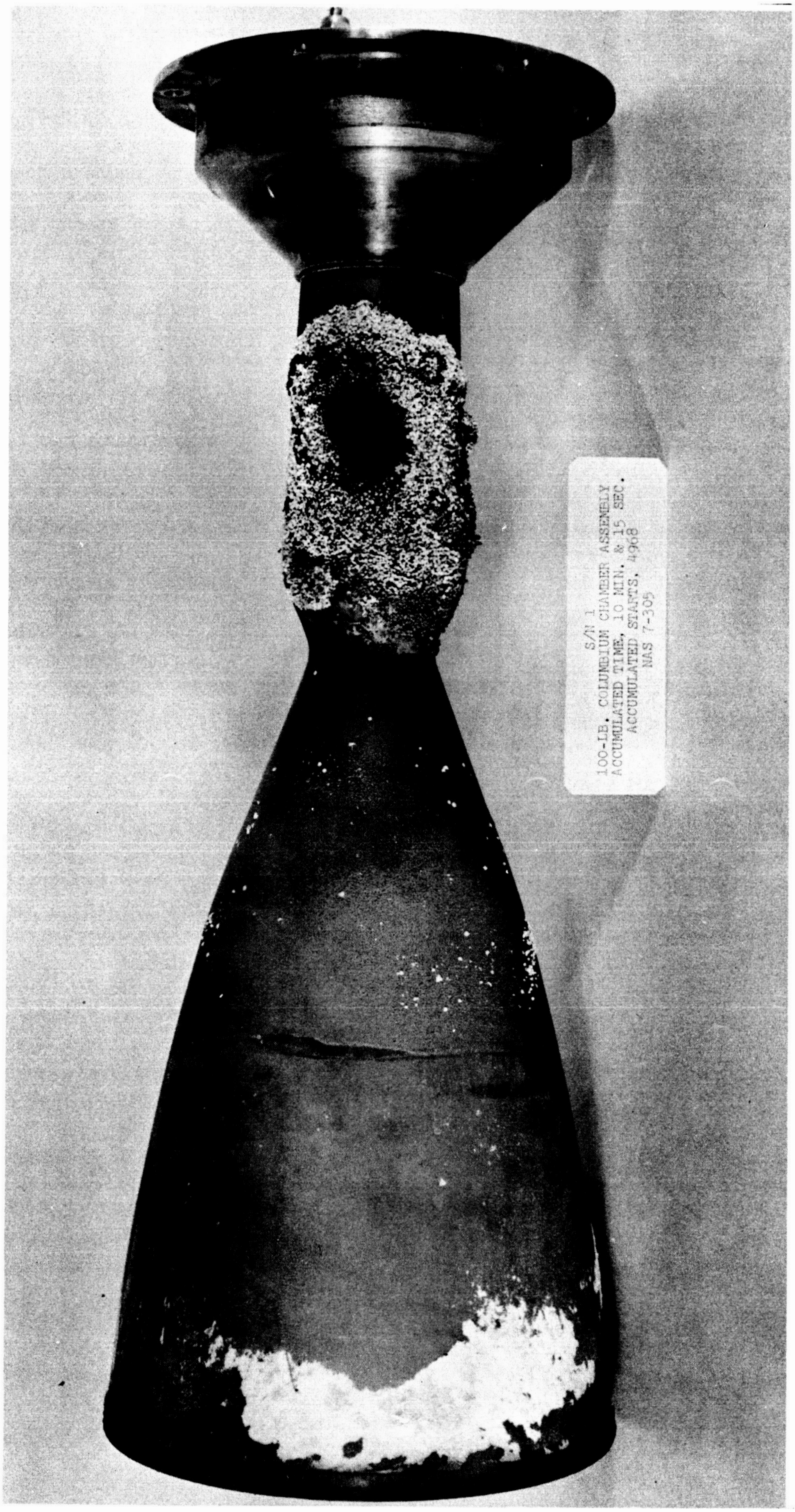


Figure VI-72. Chamber Assembly From Engine S/N 1 After Test Burnout Region

Figure VI-73. Chamber Assembly From Engine S/N 1 After Test

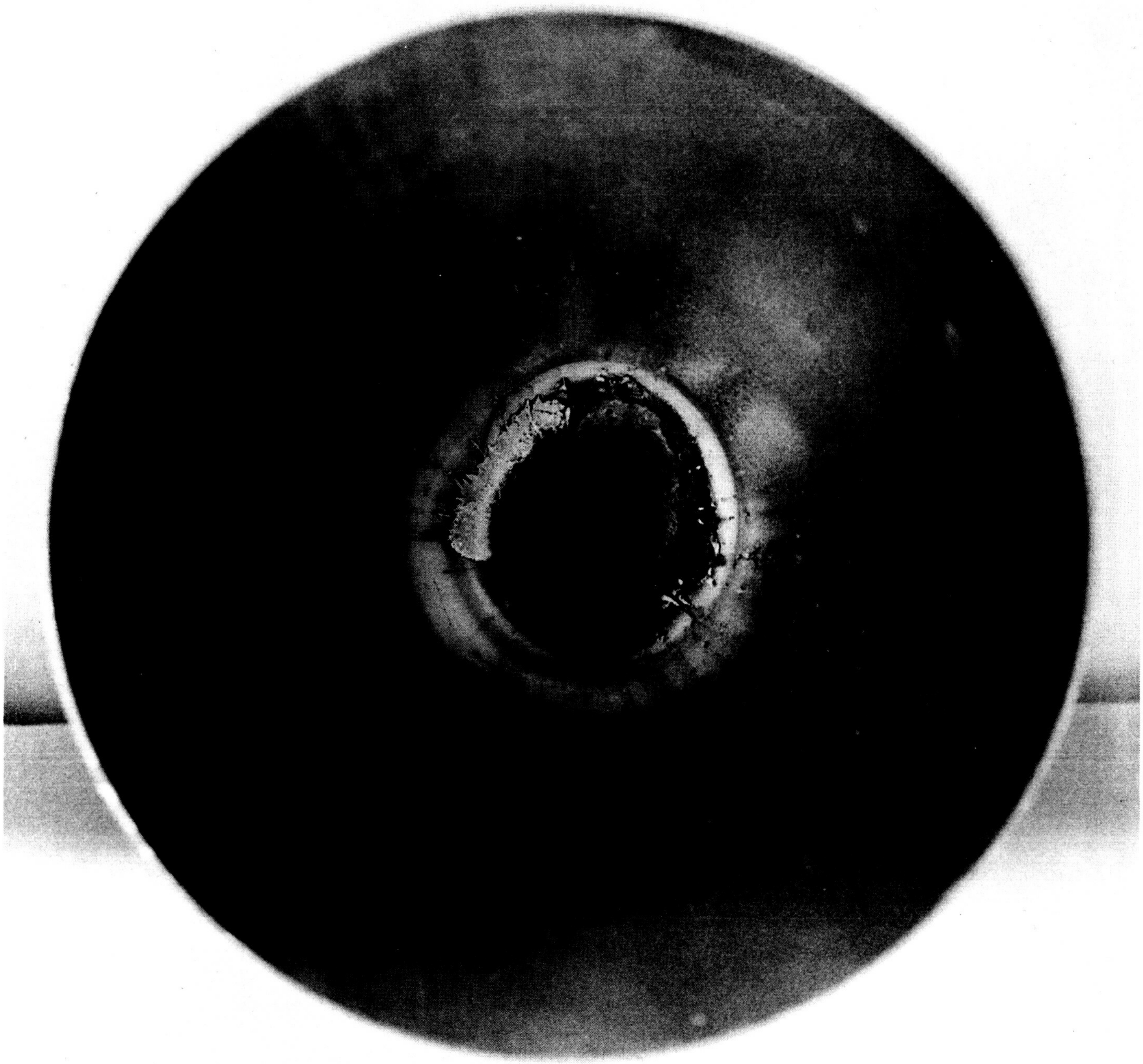


Figure VI-74. Chamber Assembly From Engine S/N 1 After Test Looking at Throat

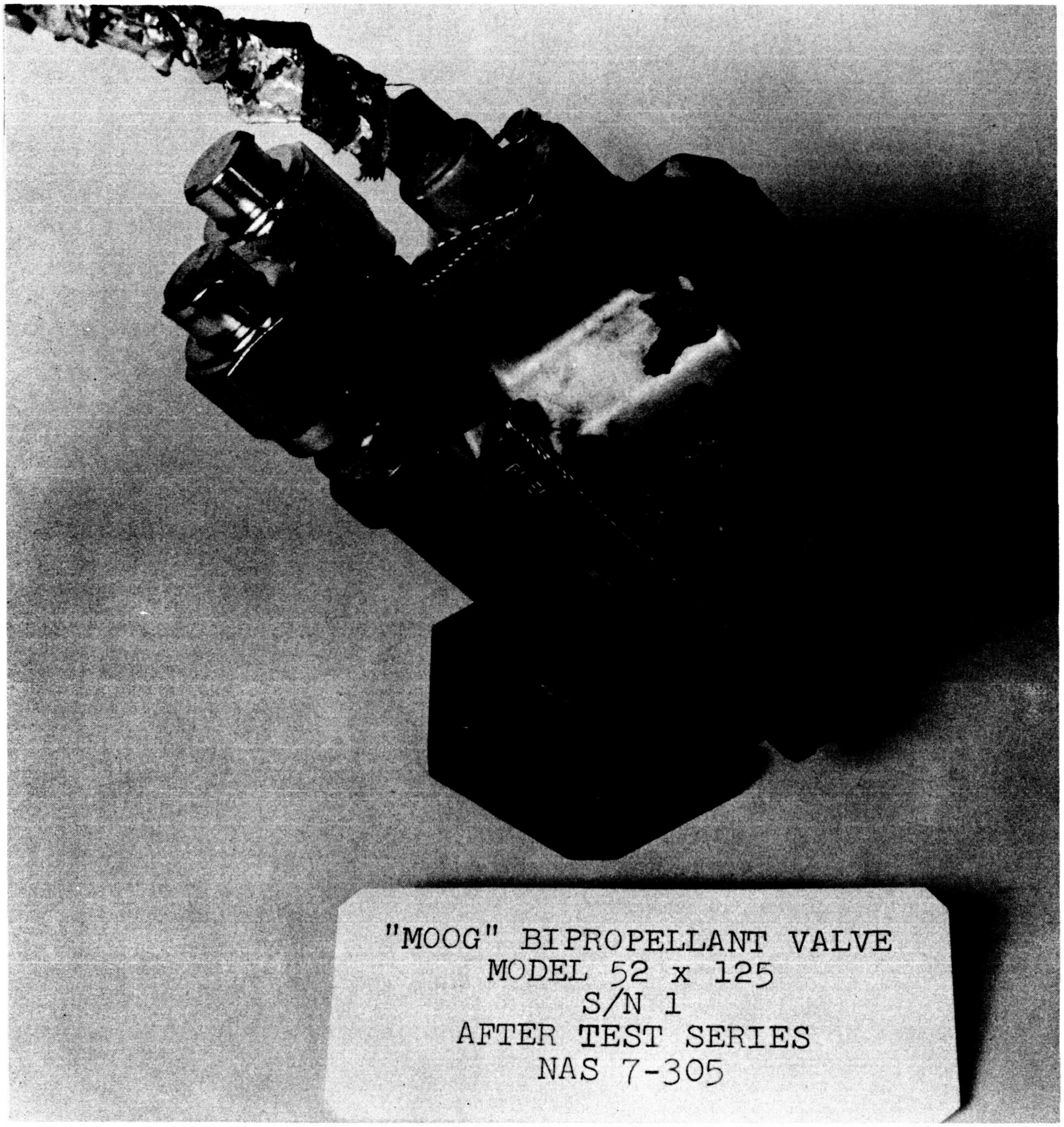


Figure VI-75. Moog Valve From Engine S/N 1 After Fire Test

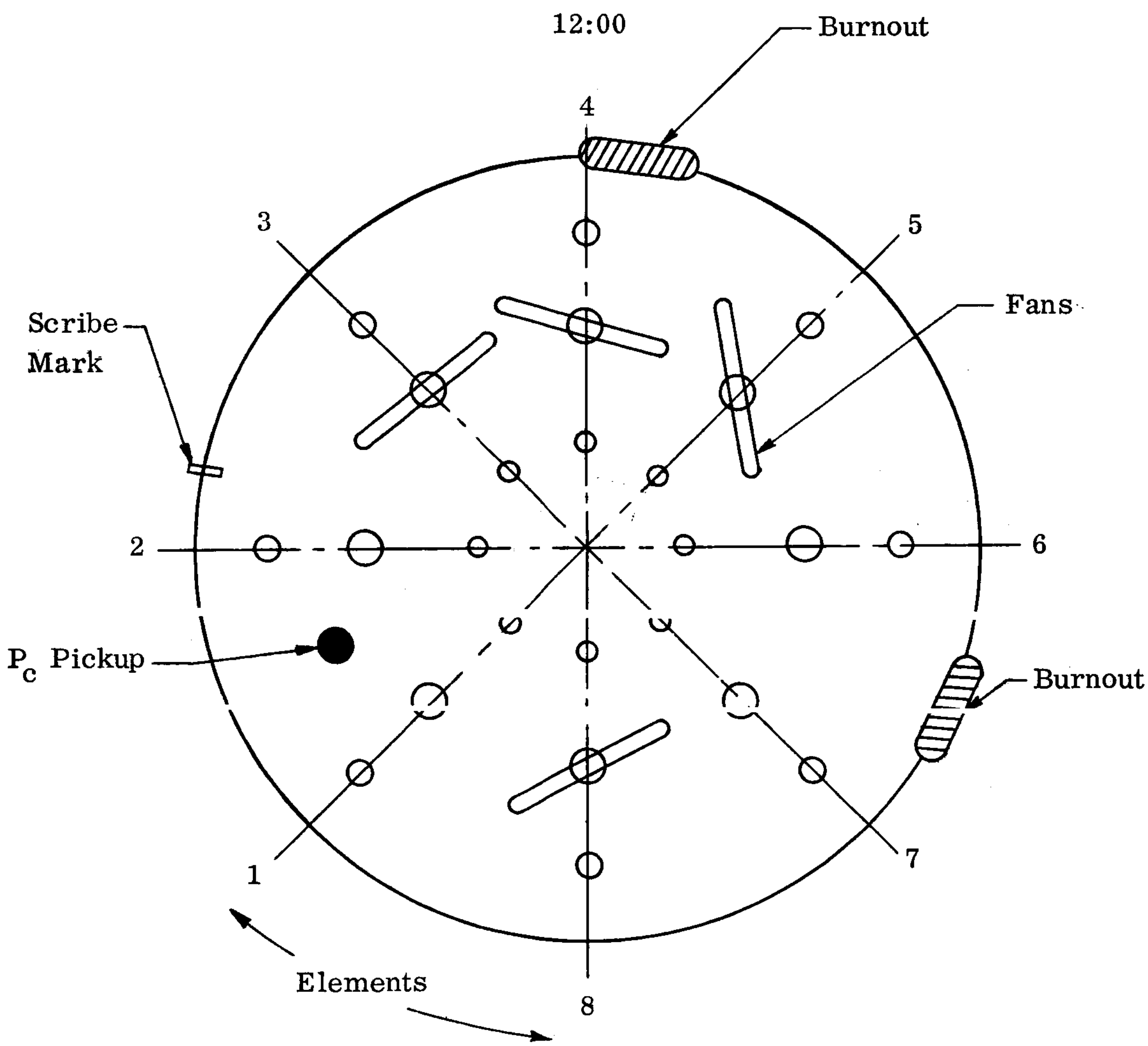


Figure VI-76. Injector S/N 1-A From Engine Assembly S/N 1 After Fire Test

C. METALLOGRAPHIC INSPECTION OF CHAMBERS - S/N 1 AND S/N 2

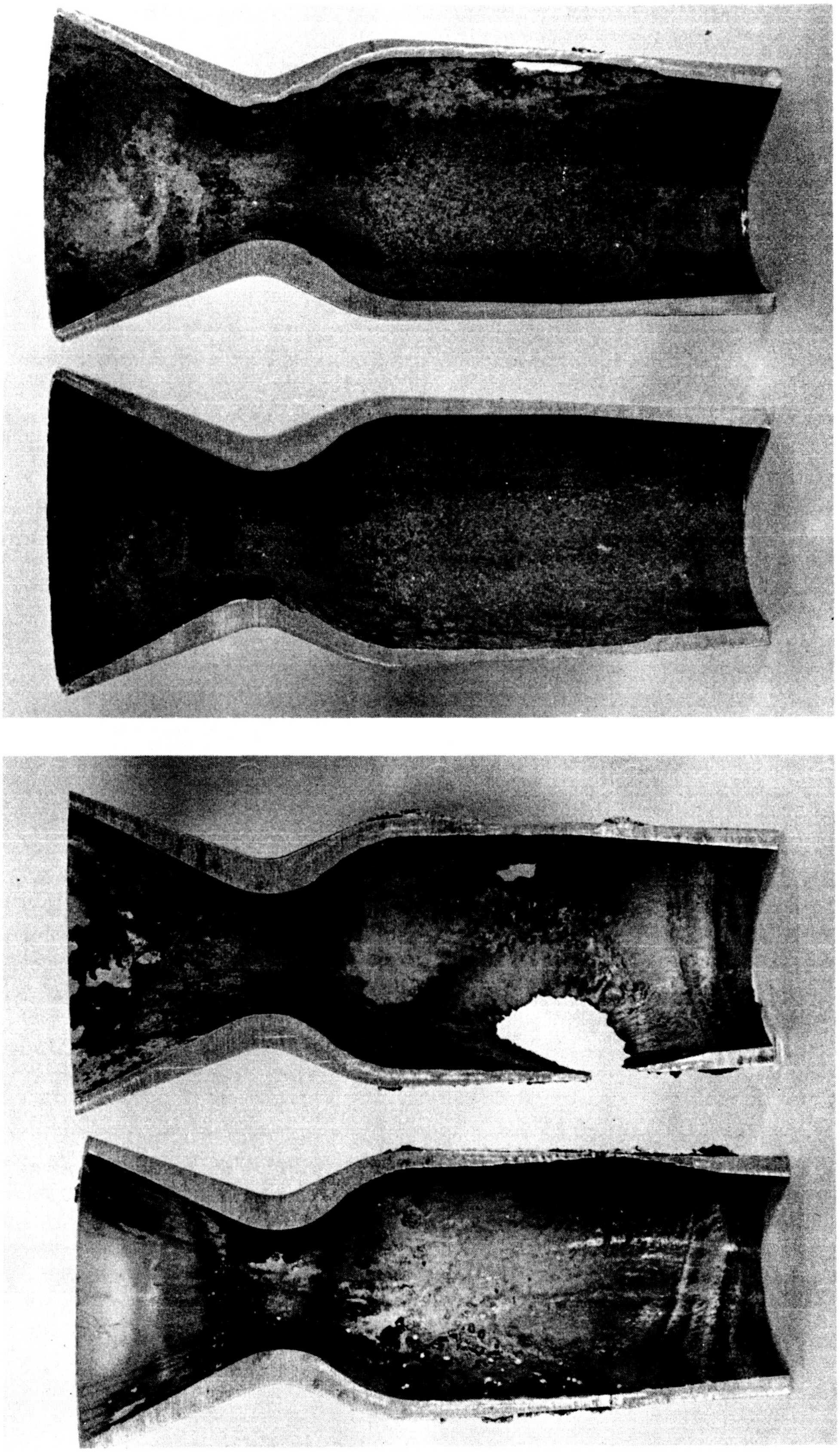
Both chambers were sectioned in half in preparation for metallurgical study of the oxidation protection provided by the silicide coating and the compatibility between the silicide coating and the alumina bubbles. These sectioned chambers are shown in Figure VI-77.

Three specimens were prepared from one halved section from each chamber. A specimen was removed from the divergent nozzle section, the chamber section near the erosion region, and the chamber section near the injector end; to serve as representative specimens along the length of each chamber.

Visual examination of these six specimens at 250 x revealed that the silicide coating was intact, provided good oxidation protection to the columbium base metal, and showed no compatibility problem with the alumina bubbles. Grain growth was present in all the specimens from chamber S/N 2 as would be expected, since this assembly had been subjected to over 30 minutes of run time. The largest grains were present in the specimen taken from the center of the chamber, adjacent to the erosion area, and thereby, the highest temperature region. Only slight intergranular oxidation was noted in the specimen taken from the divergent nozzle section of chamber S/N 2. The specimens from chamber S/N 1 revealed the original "as forged" structure with no grain growth indicated except on the specimen in the erosion area. In this specimen some grain growth had occurred and portions of the specimen showed oxidation and contamination of the substrate as would be expected under severely high temperature conditions.

These details are further described in Figure VI-78.

Photomicrographs of three of the six specimens are given in Figures VI-79, VI-80, and VI-81.



Chamber S/N 2

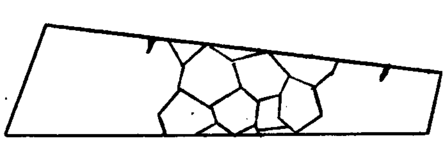
Chamber S/N 1

Figure VI-77. Columbium Chamber S/N 1 and S/N 2 After Sectioning

From Engine S/N 2

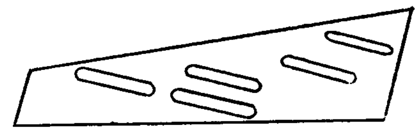
From Engine S/N 1

Specimen No.



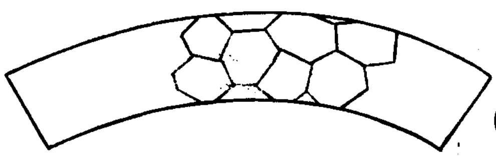
1A

Large Grains -
Slight Intergranular Oxidation
Coating Intact



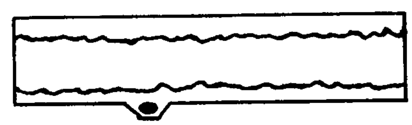
1B

As Forged Structure
No Intergranular Oxidation
Coating Intact



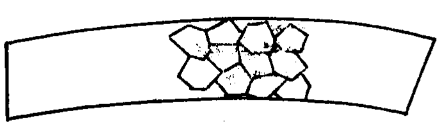
2A

Largest Grain Size
Coating Intact



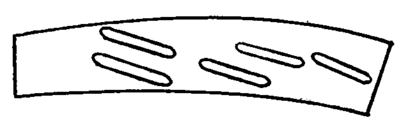
2B

Near Burnout Region -
Intergranular Oxidation
Caused By Excessive
Temperature. Foreign
Phase Diffused Into
Structure - Some
Recrystallation



3A

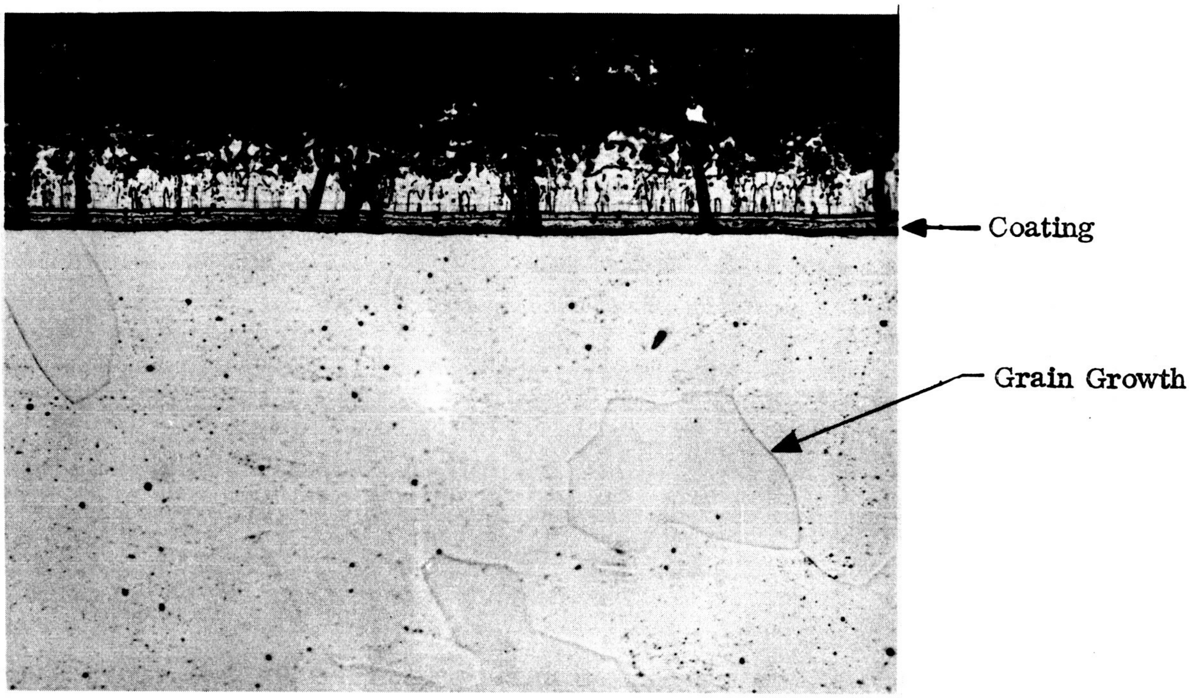
Smaller Grains
Coating Intact



3B

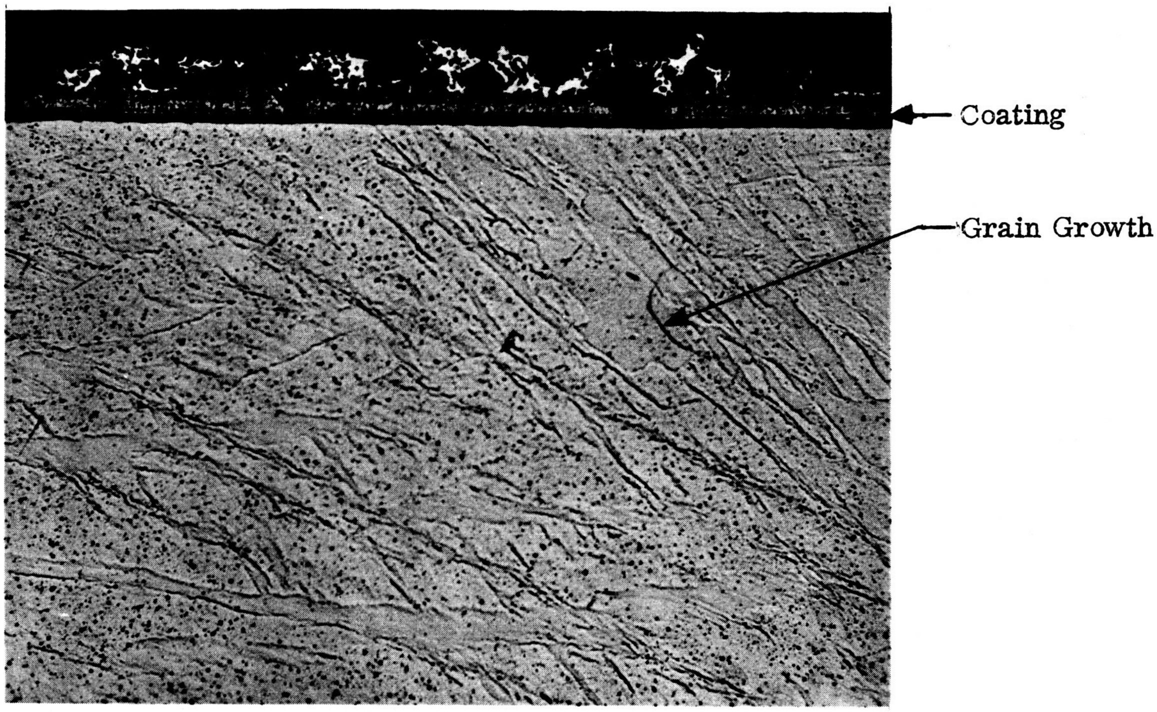
As Forced Structure
Coating Intact

Figure VI-78, Metallurgical Specimens



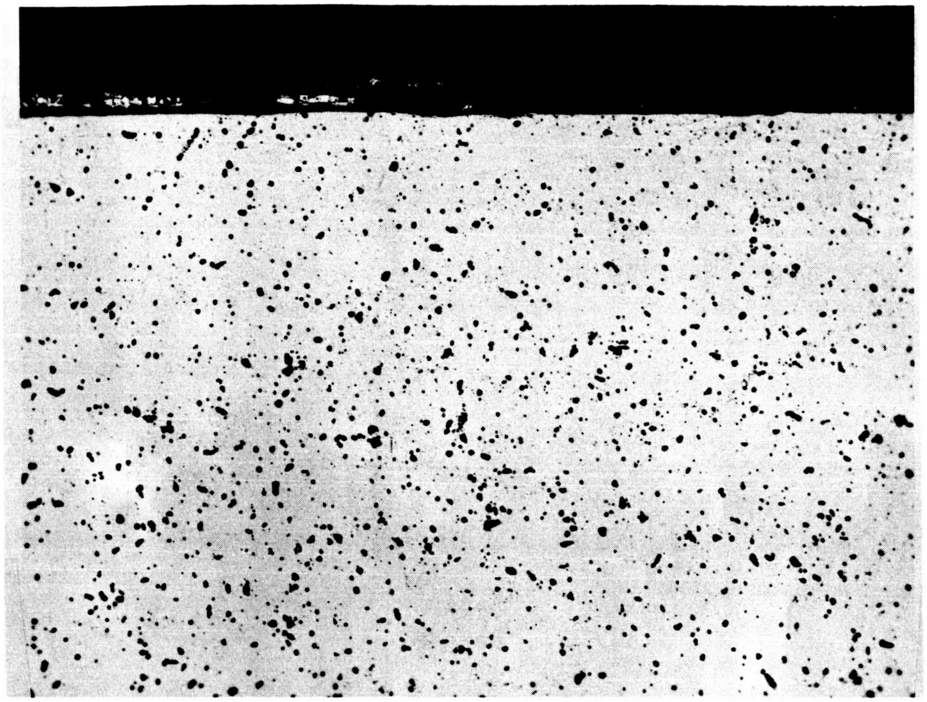
Met No. 65-1871
Mag. 100x
Etched

Figure VI-79. Photomicrograph of Modified Silicide Coated SCb 291 Columbium Chamber Fired for 30 Minutes - Section Taken From Approximate Midpoint of Inlet - O.D. Surface



Met No. 65-1871
Mag. 250x
Etched

Figure VI-80. Photomicrograph of Modified Silicide Coated SCb 291 Columbium Chamber Fired for 30 Minutes - Section Taken From Approximate Midpoint of Inlet - O.D. Surface



Met No. 65-1871
Mag. 100x
Etched

Figure VI-81. Photomicrograph of Modified Silicide Coated SCb 291 Columbium Chamber Fired for 30 Minutes - Section Taken From Area Adjacent to Burn Through - O.D. Surface

D. THERMAL ANALYSES CORRELATION WITH TEST RESULTS

A comparison of the thermocouple data from the test series has been made with temperatures obtained by thermal analyses performed on the mathematical model.

1. Injector and Propellant Valve Temperature

Temperatures in the proximity of the injector and propellant valve are of particular interest during pulse mode operation and also during the extended heat soakback period following engine shutdown. Temperature correlations in these areas are presented in Figures VI-82 through VI-87.

Shown in Figure VI-82 are the maximum valve temperatures as a function of duty cycle during operation and also during the subsequent extended soakback period. Since the test data for a duty cycle of 1.0 was obtained from the 29 minute firing and the shutdown period which followed, the chamber burnout and the hot exhaust gases flowing past the valve caused higher valve temperatures than would normally be anticipated. At a 0.1 duty cycle during the operating condition, the analytic results are in good agreement with test data but during the shutdown period they overpredict the maximum valve temperatures which were recorded. Two possible reasons for the overprediction are as follows:

(1) More heat is conducted into the test stand than what was arbitrarily assumed for the design condition. The design boundary condition assumed the mounting flange was either insulated or held at a maximum of 400°F.

(2) The mathematical model does not quite simulate the shutdown transient in so far as it appears to be slow in time responses. The 0.01 duty cycle test data was not included in the figure since there was insufficient pulsing to obtain valid data.

Figure VI-83 is similar to Figure VI-82 except that it presents the maximum temperatures in the vicinity of the injector. Thermocouples T-1 and T-2 were located between the mathematical nodes 60 and 62. The results looked good, except once again the maximum shutdown temperature for a duty cycle of 1.0 was extremely high because of the problems encountered during the 29 minute firing.

Again it would appear that analysis overpredicts the heatup during coast and this again is partially due to the more stringent boundary conditions imposed on the mounting flange of the analytic model then that in test.

Figure VI-84 shows the shutdown transient in the injector and the valve during the heat soakback period following a steady state firing. Analytic results for an engine design with alumina bubbles and also another design without the bubbles are presented since both had been reviewed in support of the choice of the design. Since most of the bubbles were expended during the test firing, it is reasonable to expect the injector cooldown to be somewhere between the analytic results for these two engine designs. The chamber burnout during test probably caused additional heat to reach the propellant valve, causing it to overheat.

Figure VI-85 illustrates the injector and valve shutdown transient following a pulse mode operation of 0.1 duty cycle. The correlation between analysis and test data is fairly good.

Following the test series shown in Figures VI-86 and VI-87, the mathematical model was subjected to the same duty cycle and as nearly as possible, the same boundary conditions as in test, in order to correlate analysis with test data. Except for thermocouple T-8, the valve correlations shown in Figure VI-86 appear to be very good. The injector results presented in Figure VI-87 are very interesting in so far as trends and levels are excellent except that a substantial increase in heating or decrease in the cooling effectiveness is evident in the last two runs. It is also worthy of note that a substantial increase in performance was indicated in these runs and that the chamber burned out at this time.

2. Fiberglass Wrap Temperature

The temperature transient on the surface of the fiberglass wrap was also obtained during the 29 minute engine firing. This test data, which was recorded by thermocouple T-36, is presented in Figure VI-88. Some analytic results for the corresponding node 47 on the mathematical model are also shown in the figure. Since the engine was designed to withstand a long duration firing, a steady state analysis was performed to obtain the equilibrium temperature distribution throughout the chamber assembly. The transient temperatures were only determined for the initial 400 seconds of firing. Therefore only the first 6.67 minutes of the time history for node 47 is available for correlation with test data. During this period, the correlation is very good. An extrapolation of the analytical curve up to about 11 minutes of firing would also show good agreement.

The analytical steady state temperature of 330°F for this node is also indicated in the figure. Although the test results at the end of the firing are somewhat higher than this predicted equilibrium temperature, the hot gases flowing past the outer surface caused the temperature to be higher than expected. The distinct increase in the slope of the test data during the 12th to 15th minute of the firing seems to verify the fact that unusual external heating occurred during this period. The predicted steady state temperature would have shown much better agreement had this incident not occurred during the test firing.

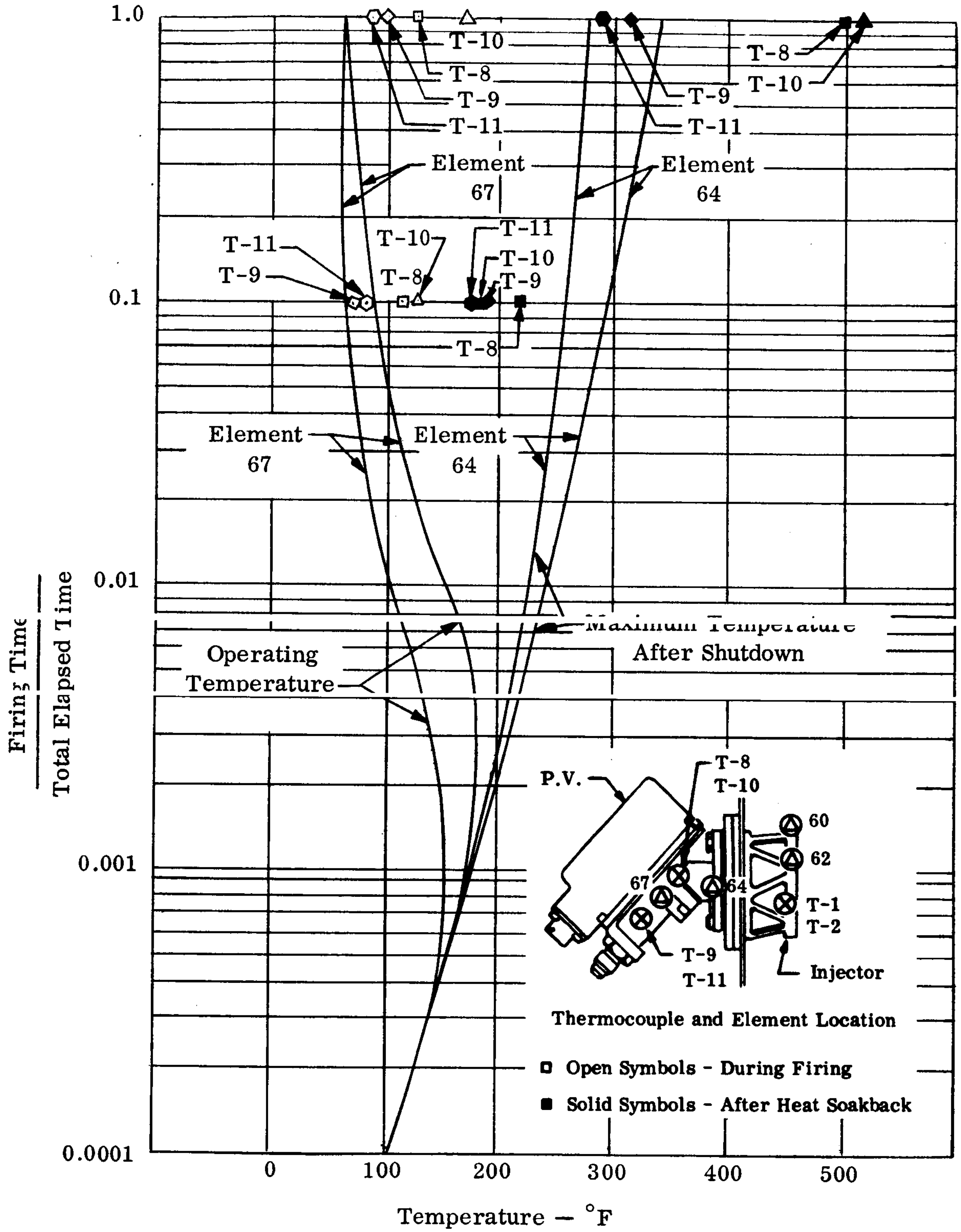


Figure VI-82. Propellant Valve Temperature versus Duty Cycle

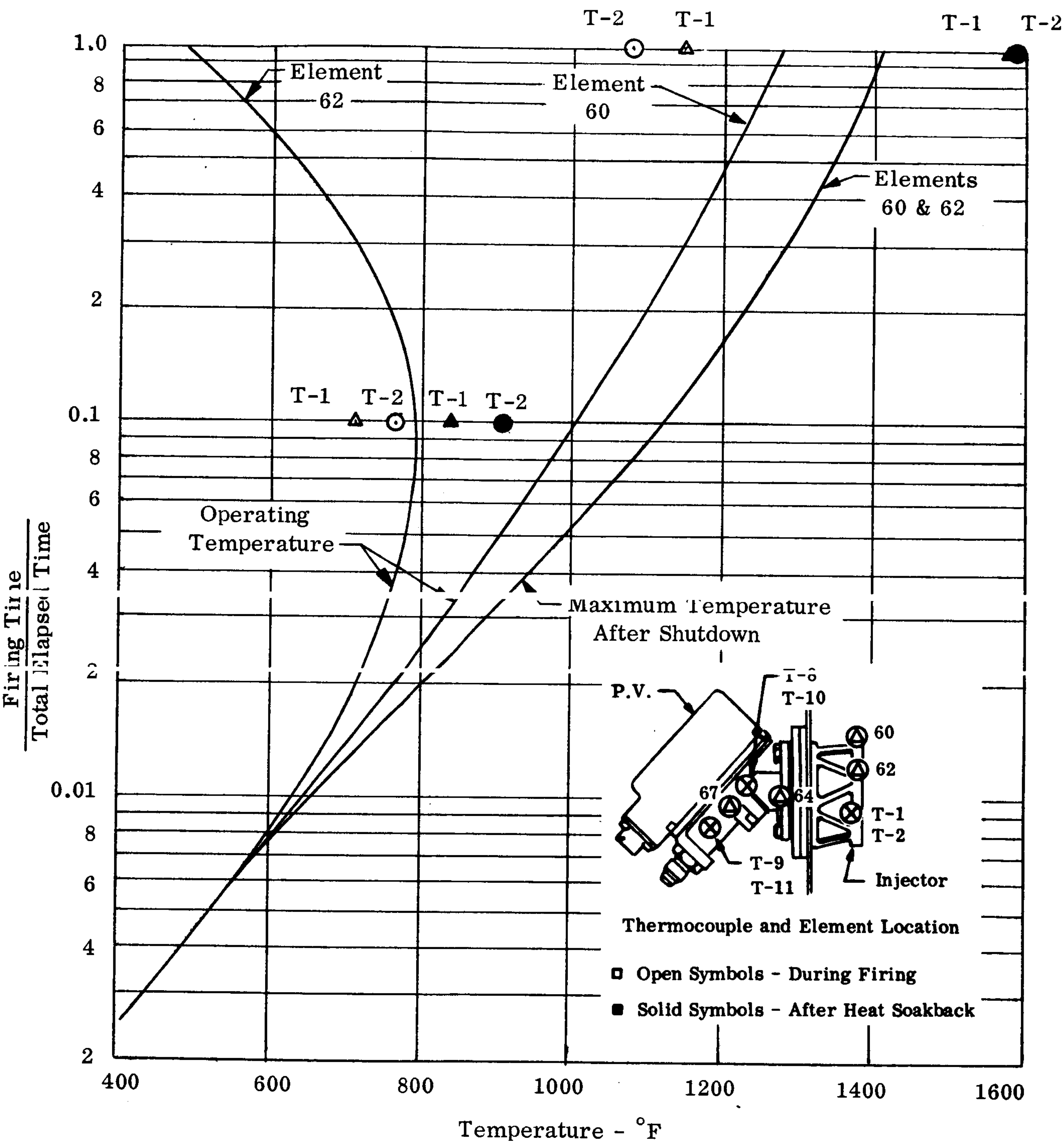


Figure VI-83. Injector Temperature versus Duty Cycle

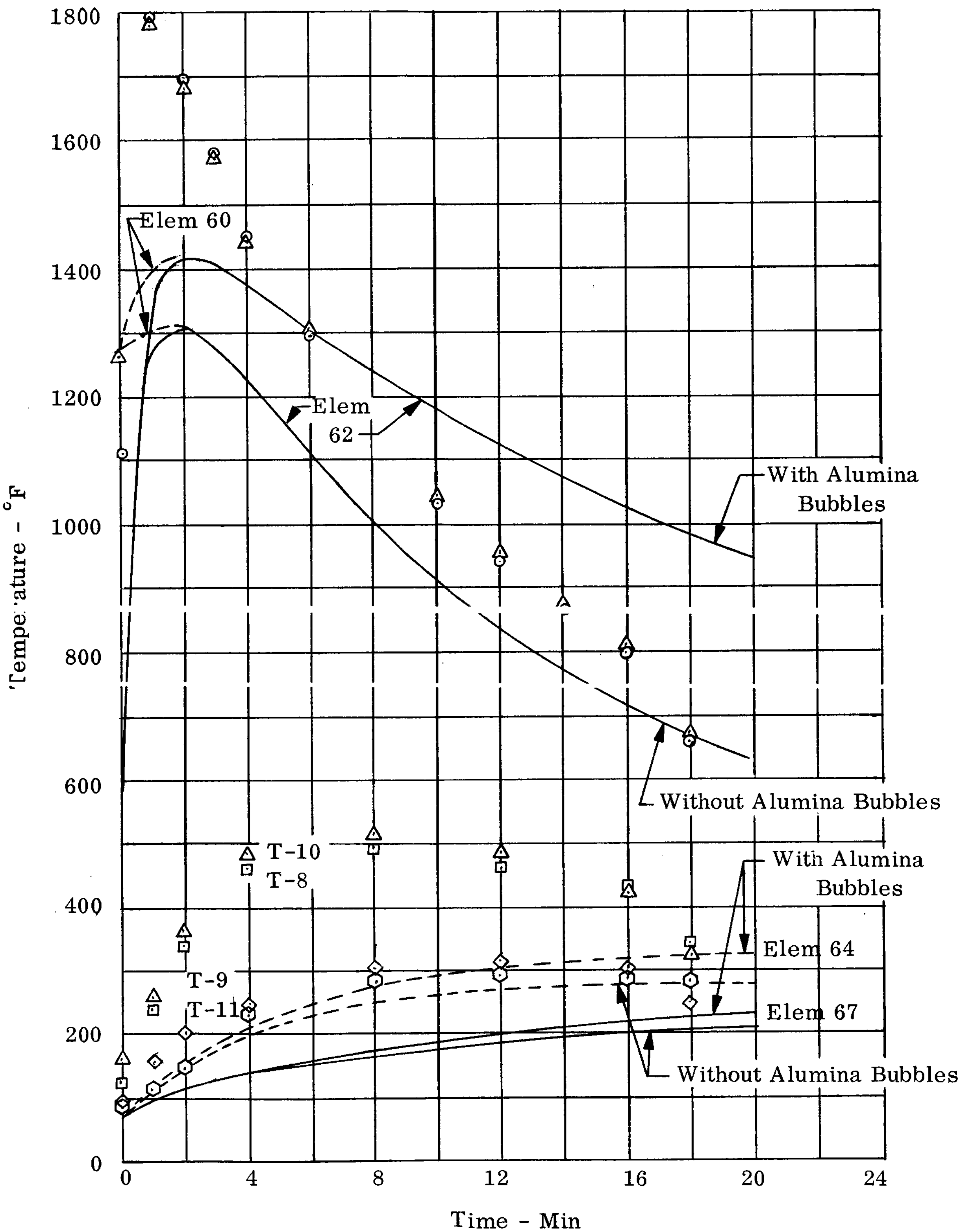


Figure VI-84. Injector and Propellant Valve Temperature Time History Cooldown After Steady State Firing (Duty Cycle = 1.0)

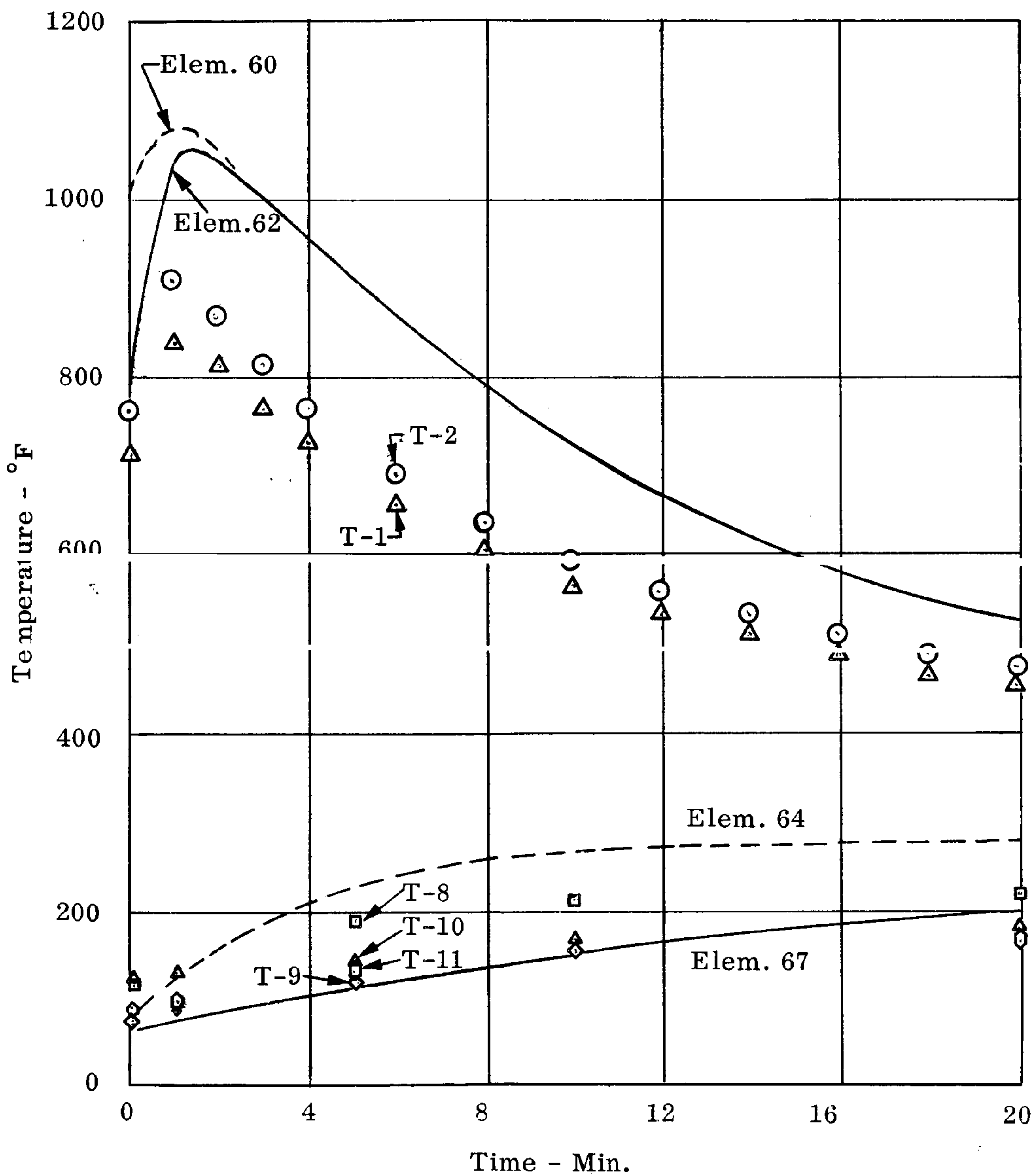


Figure VI-85. Injector and Propellant Valve Temperature Time History Cool Down After Steady State Firing (Duty Cycle = 0.1)

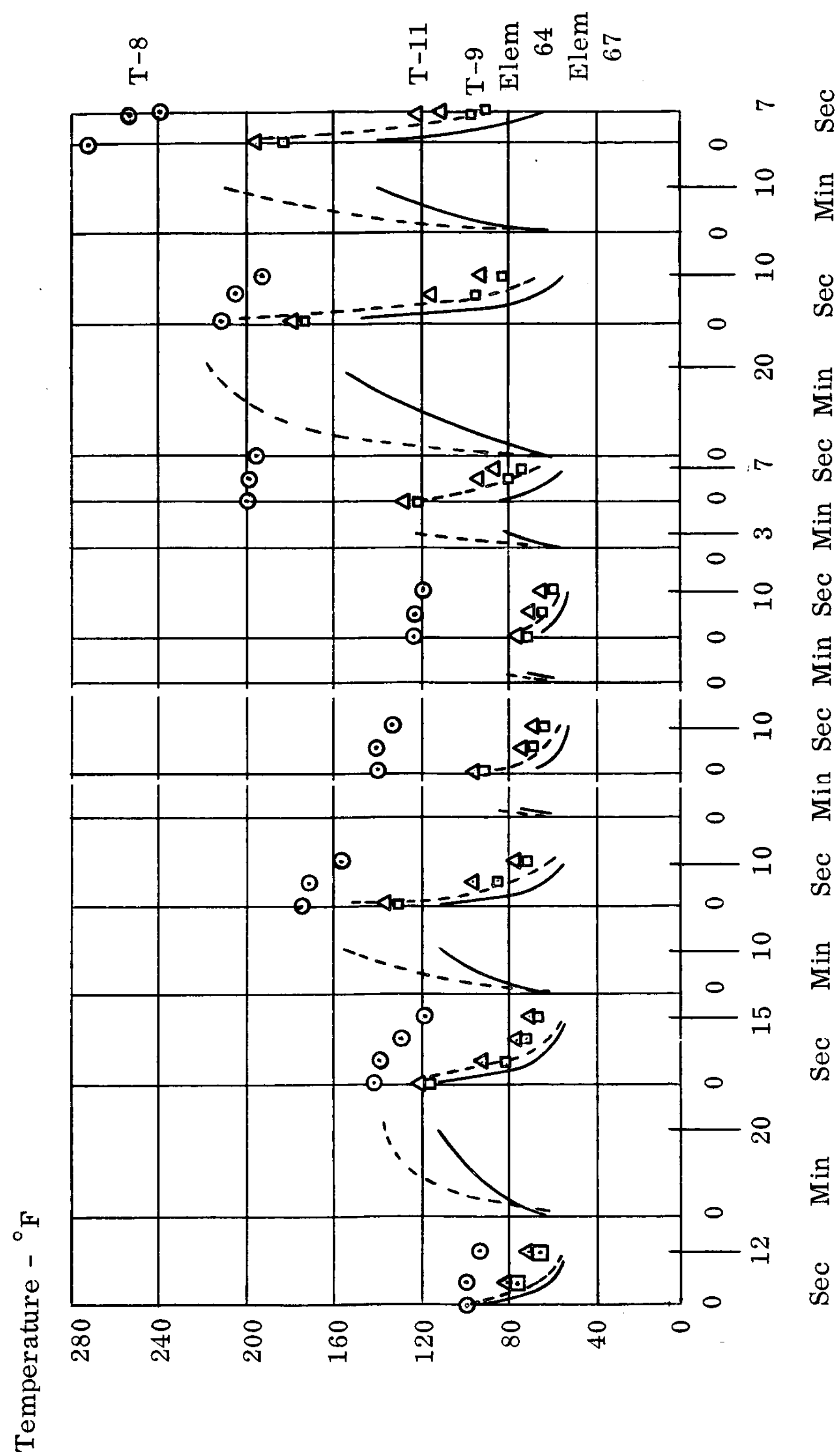


Figure VI-86.. Propellant Valve Temperatures

Run No. 1722

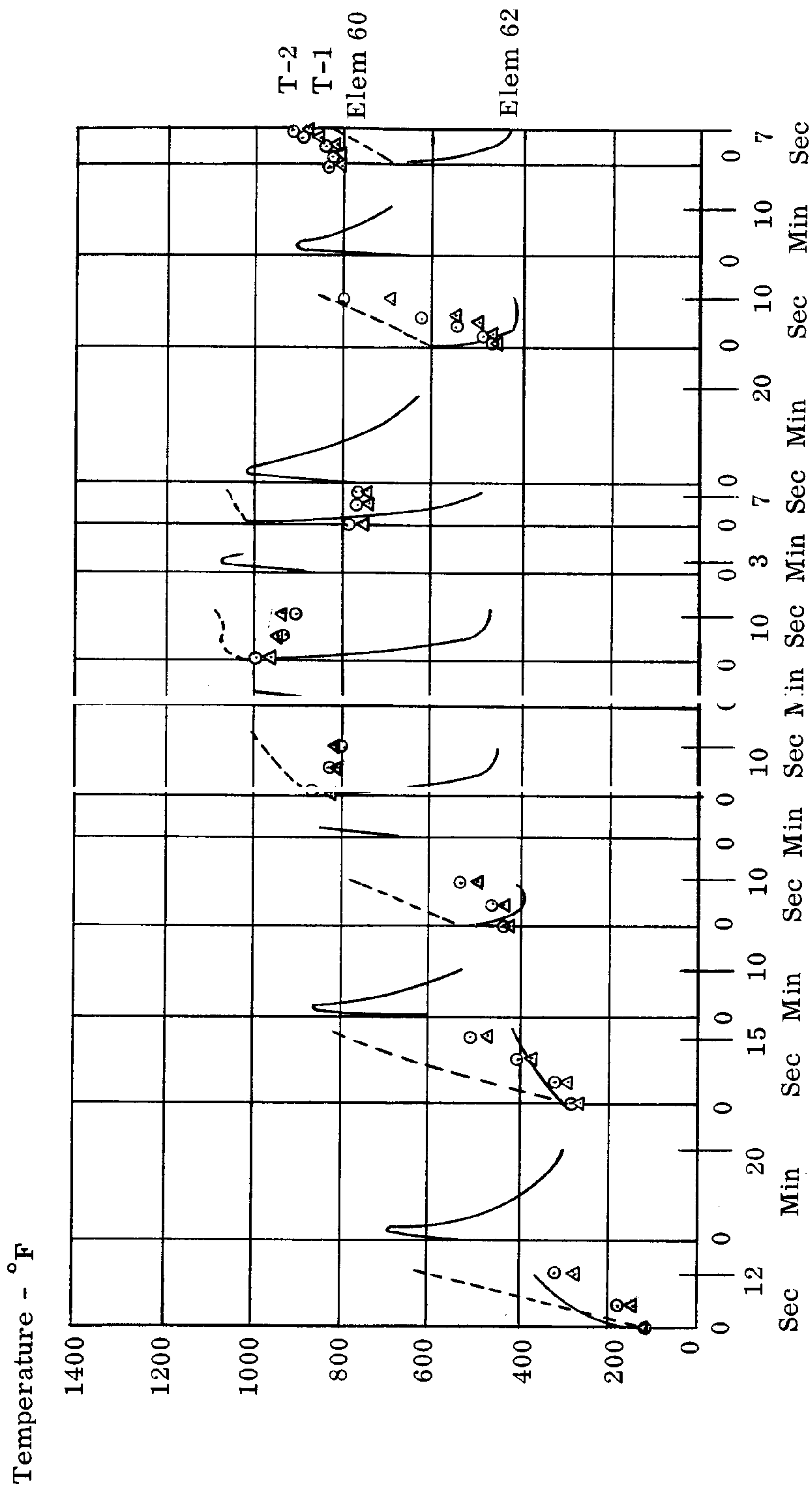


Figure VI-87. Injector Temperatures

Run No. 1722

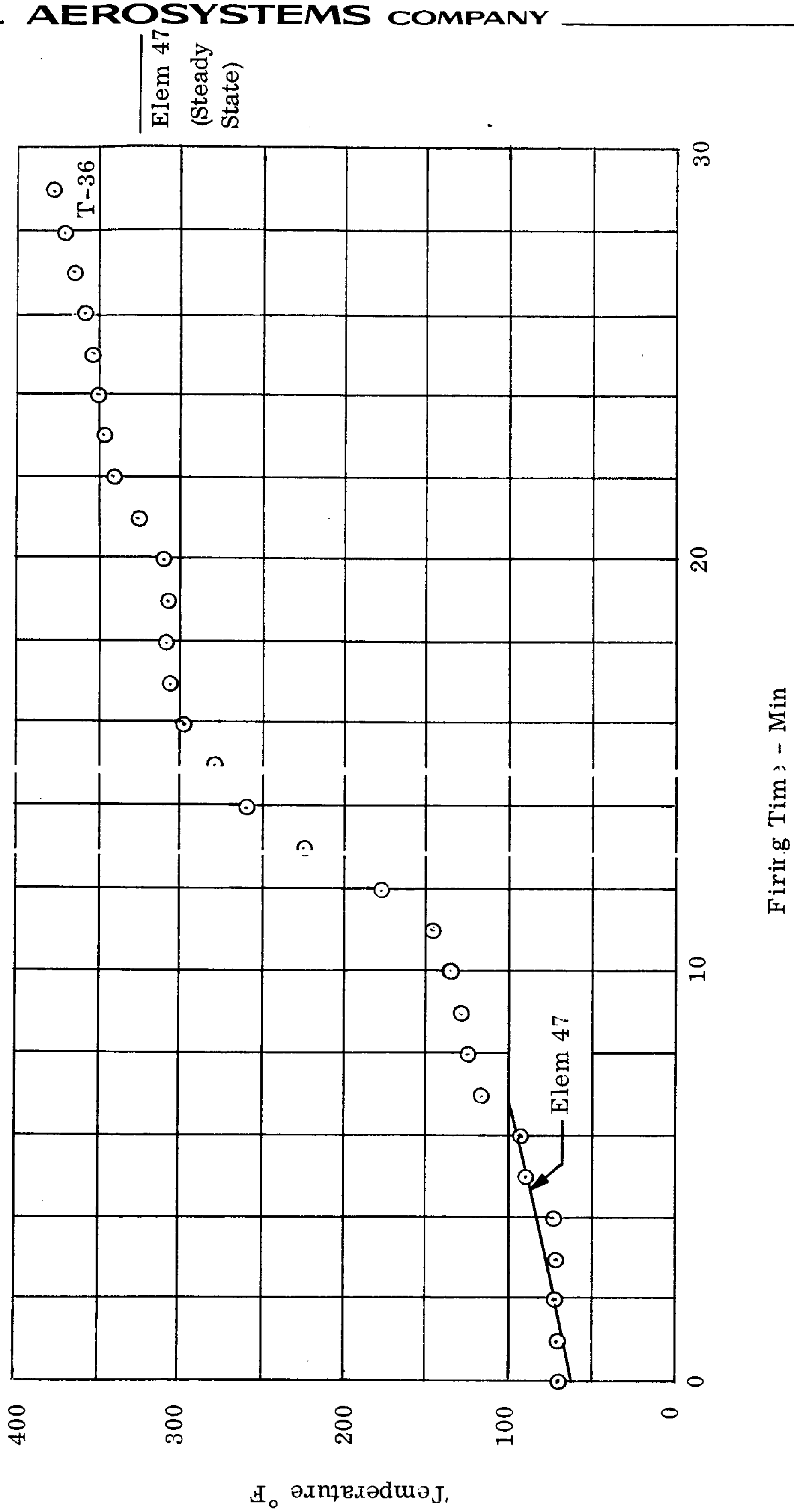


Figure VI-88. Fiberglass Wrap Temperature Engine S/N 2

E. PERFORMANCE AND INSTRUMENTATION

1. Test Summary

Listed below is a summary of the total number of tests performed on the two prototype demonstration engines.

Run No.	Date	Run Duration (sec)	
2E-S	Engine S/N 2		
1684	10-19-65	6.3	
1685	10-19-65	31.2	
1686	10-21-65	16.0	
1687	10-21-65	5.8	
1688	10-21-65	1748.0	
1689	10-21-65	2.0	
	Total Time	1809.3 sec	(30.1 min)
	Engine S/N 1		
1691	10-29-65	4.9	
1692	11-3-65	5.6	
1693	11-3-65	30.0	
1694	11-3-65	90.0	3000 Pulses (0.030 On, 0.27 Off)
1695	11-3-65	100.0	1000 Pulses (0.100 On, 0.90 Off)
1696	11-4-65	15.0	150 Pulses (0.100 On, 9.9 Off)
1697	11-4-65	5.1	
1698	11-4-65		10 Pulses (0.010 On, 60 sec Off)
1699	11-4-65		10 Pulses (0.020 On, 60 sec Off)
1700	11-4-65	1	10 Pulses (0.030 On, 60 sec Off)
1701	11-4-65		10 Pulses (0.040 On, 60 sec Off)
1702	11-4-65		4 Pulses (0.010 On, 60 sec Off)
1703	11-4-65	4.8	
1704	11-4-65	98.0	Appollo Command Module Duty Cycle
1705	11-5-65	10.2	
1706		10.3	
1707		20.3	
1708		20.8	
1709		20.2	
1710		20.3	
1711		21.1	
1712		20.2	
1713		20.3	

Run No.	Date	Run Duration (sec)
1714		20.4
1715		20.1
1716		15.3
1717		10.3
1718		10.8
1719		10.3
1720		7.1
1721		10.5
1722		7.2

Total Time 631.2 sec (10.5 min)

Total No. of Starts = 4906

2. Maximum Impulse Bit

The capability of this engine to develop small impulse bits has been demonstrated. The thrust trace from the second 0.010 second pulse from Run No. 1702 has been integrated to determine the impulse bit. This impulse bit for a 10 millisecond electrical signal to the propellant valve is 0.002 lb/sec. This is referenced in Figure VI-89.

3. Engine Performance

The performance for Engine S/N 1 and S/N 2 is shown in Figures VI-90 and VI-91. At a nominal mixture ratio of 1.6 the characteristic velocity is 5280 ft/sec, the $I_{sp\infty}$ is 291.5 seconds for S/N 1, 5275 ft/sec and 291 seconds for S/N 2.

4. Instrumentation Accuracies

The following instrumentation accuracies apply to the demonstration engine data:

$F = 2.2\%$ $\quad P_c = 1.2\%$

$I_{sp} = 2.2\%$ $\quad w_T = 0.5\%$

$C_f = 2.5\%$

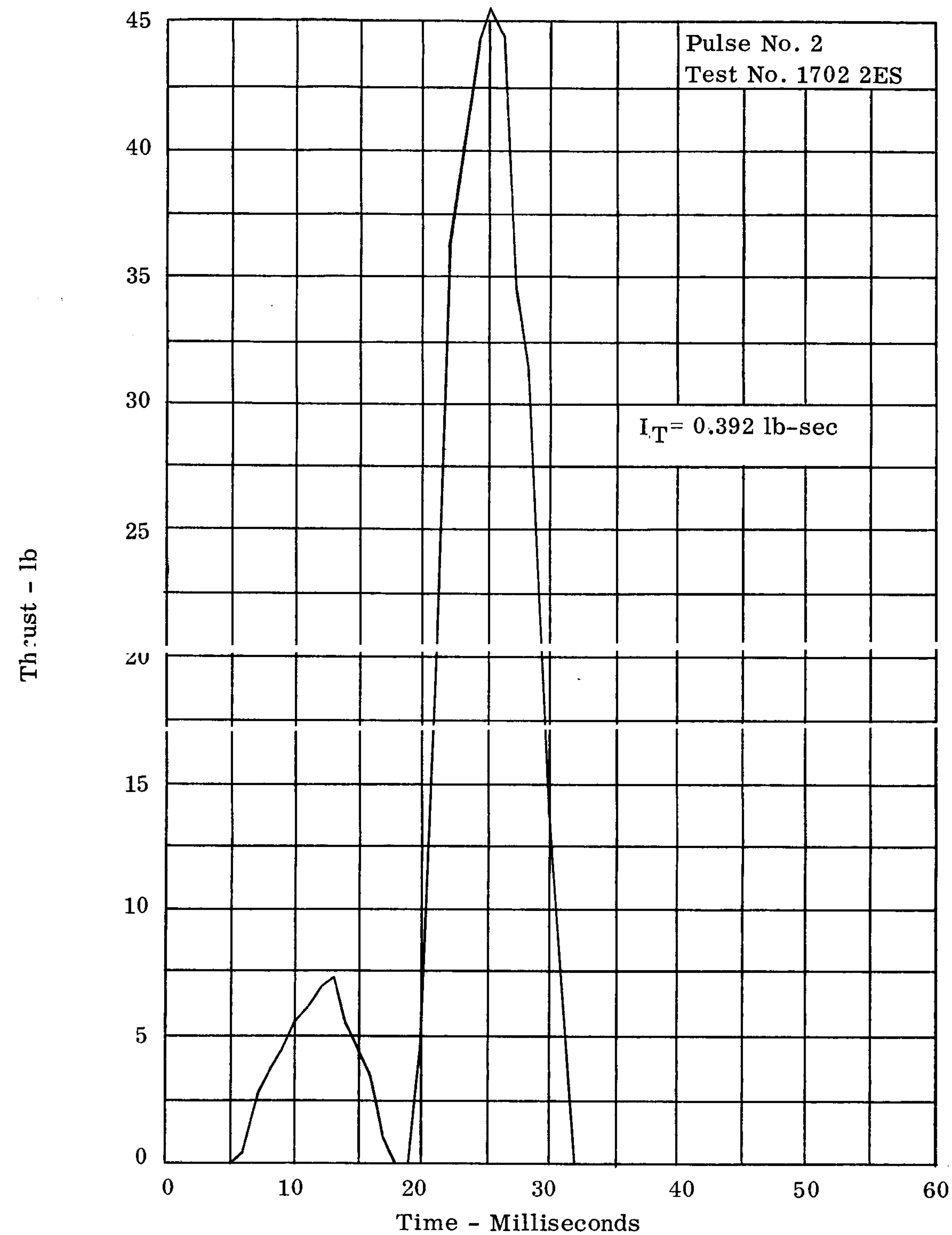


Figure VI-89. Impulse Bit 0.010 sec ON Engine S/N 1

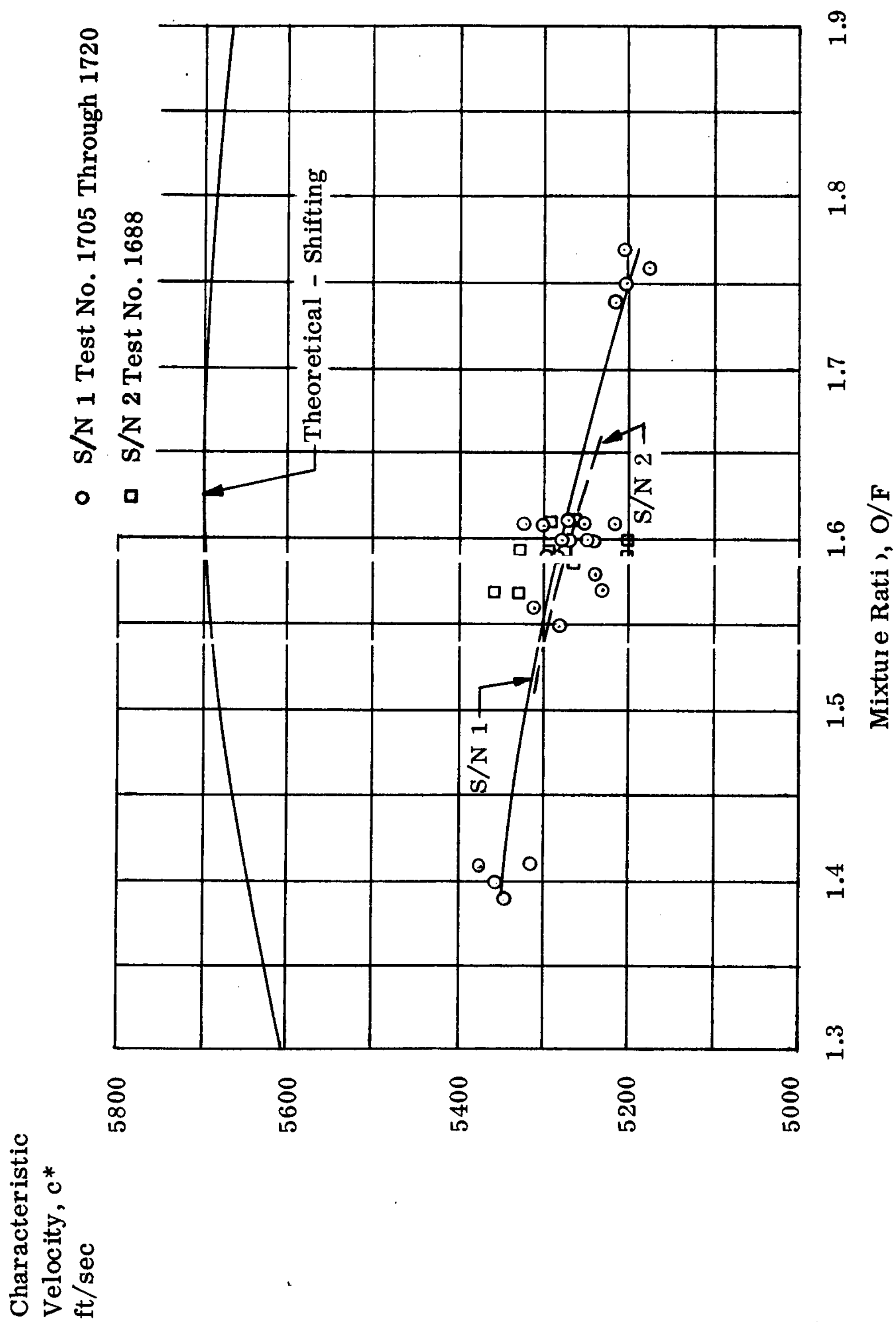


Figure VI-90. c* versus Mixture Ratio Engine S/N 1 & 2

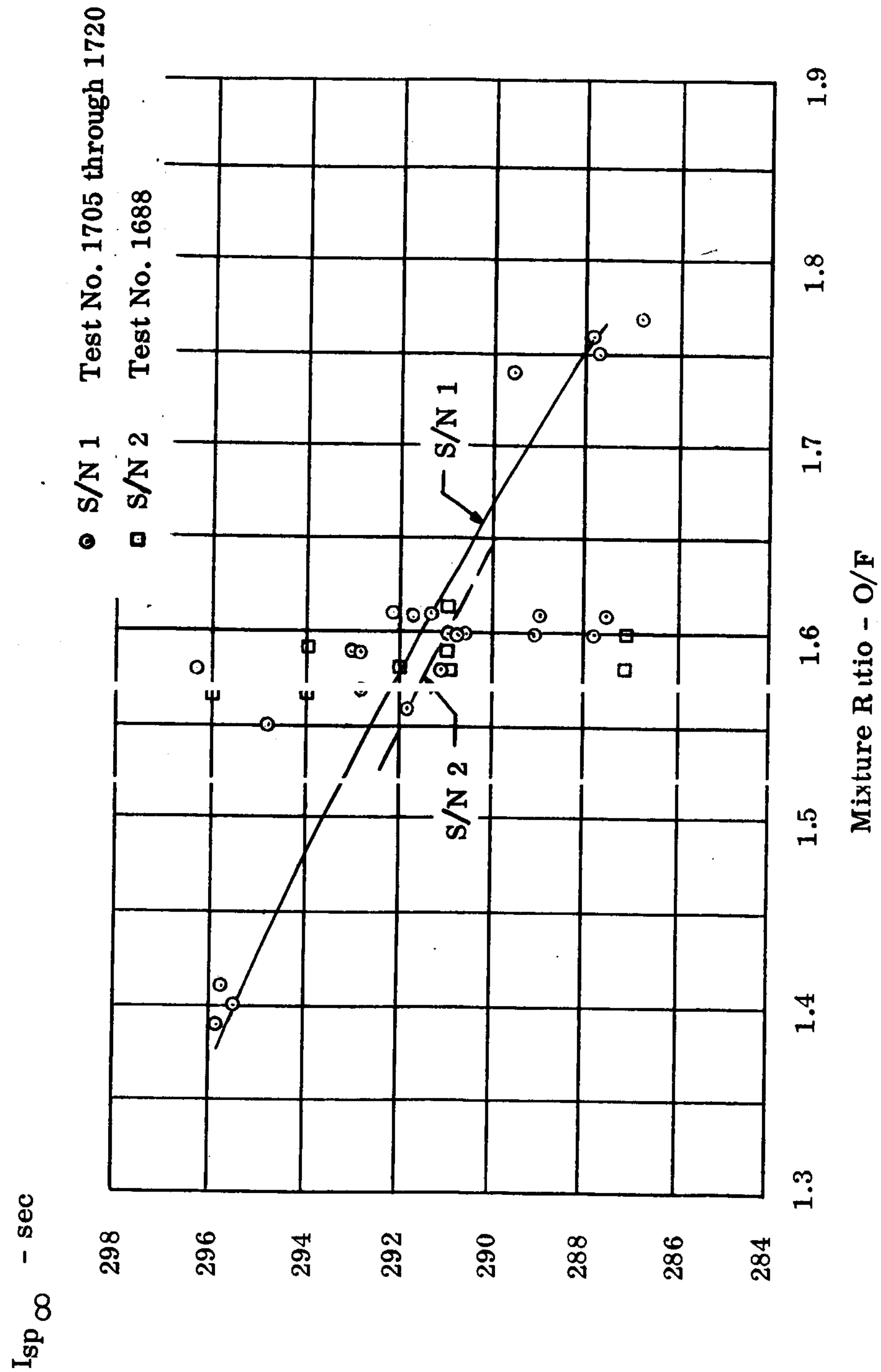


Figure VI-91. I_{sp_∞} versus Mixture Ratio Engine S/N 1 & 2

VII. TRIPS AND VISITS

Following is a summary of the trips, visits and meetings during this program:

1. June 1964

A brief meeting was held at JPL (Los Angeles) on 6-24-64 with the BAC Chief of Structures - Rockets attending. The purpose of this meeting was to provide BAC with information concerning pyrolytic graphite technology. On 6-25-64 a meeting was held at MSC (Houston) with the BAC, Chief of Structures - Rockets and BAC Chief of Applied Technology - Rockets attending. The purpose of this meeting was to provide BAC with information concerning thermal and dynamic environments induced by the Apollo and Gemini vehicles on the secondary propulsion units.

2. September 1964

Bell Aerosystems Company personnel visited NASA-JPL on 21 September 1964 for a technical review of the progress during the first quarter. The importance of incorporating ignition "spike" investigations in this program was emphasized during this review.

3. October 1964

Bell Aerosystems Company personnel visited NASA-Houston on 14 and 15 October 1964 to discuss the ignition spike problem. The results of the NASA-Houston precombustor test series were reviewed and indicated the capability of the precombustor to reduce or eliminate the ignition spike during altitude starts. A brief meeting was also held at NASA-Houston with personnel from Vitro Laboratories, New Jersey, to discuss their coating capabilities.

Bell Aerosystems Company personnel visited IIT Research Institute, Chicago, Illinois, on 28 October 1964 to review the coating process they were developing.

4. December 1964

The Second Quarterly review was held at Bell on December 18, 1964 with Messrs. J. Flanagan, NASA Headquarters, and D. Evans, NASA-JPL in attendance.

5. March 1965

Bell personnel visited IIT Research Institute, Chicago, Illinois on 3 March 1965 to review the hafnium-tantalum clad chamber test results.

The Third Quarterly Review was held at BAC on 25 March 1965 with Messrs. R. Rollins, NASA Headquarters, D. Evans, NASA-JPL and L. Como in attendance.

6. May 1965

Design Review at JPL.

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Whereas the objectives of the subject program were not fully attained, it is with much satisfaction that the following conclusions are reached..

1. The program did analytically determine an engine design concept which satisfies a wide spectrum of applications in reaction control and spacecraft maneuvering systems, suitable for installation either internal or external to the vehicle, which is capable of unlimited duty cycle operation.

2. The prototype engine test program did in fact demonstrate the feasibility of an engine in the buried configuration at the 100 lb thrust level with the following limitations.

   (a) Additional effort must be expended in fabrication of small injectors, and/or new injector screening techniques must be developed to improve and measure the quality of any particular injector, thereby minimizing damage due to "streaking".

   (b) More effort must be expended to determine the time, temperature capability of the selected coated refractory metal system and/or effort expended in the promising new high temperature coated/clad refractory metal systems.

The 29 minute engine firing must certainly be considered a very significant milestone, especially considering that it was accomplished utilizing an injector acknowledged to be less than perfect prior to test.

3. The injector selected has been demonstrated to be throttleable over a 4:1 range.

4. The concept selected and the learned technology is considered applicable to a family of engines from 25 to 1000 pounds thrust.

The referred to "learned technology" evolved and/or demonstrated during the program includes.

(a) A demonstration of the adequacy of the selected bipropellant valve.

(b) The development of the unique unbalanced triplet coolant technique which eliminates the need for very small discreet coolant holes.

(c) The demonstration of the composite insulation technique in consideration of overall conductivity, temperature capability, and size/volume relationship.

(d) The compatability of the selected insulation materials with the coated refractory metal system selected.

(e) The ability to analytically define a thermal model of a given engine configuration and predict temperatures at various stations with a high degree of confidence.

It is further stated that whereas the test program fell short of demonstrating the 1 hour operating life as an insulated engine, we believe there is a high probability the life would have reached or exceeded this goal uninsulated, in which case it would be operating at approximately 2400°F instead of 2900°F.

B. RECOMMENDATIONS

With the aforementioned conclusion that the design concept has been proven feasible, the first and foremost recommendation is that the concept be adapted for a specific application and that a development program be initiated.

In order to evolve a more reliable, more optimum design and consideration of the various other conclusions reached, the following areas of interest should be explored at the 100 pound thrust level.

(1) Improvement of injector fabrication techniques.

(2) Refinement of injector impingement inspection techniques.

(3) Further definition of the time/temperature capabilities for the coated refractory metal system selected.

(4) Evaluation of promising higher temperature capability materials to increase reliability margin.

(5) Definition and evaluation of promising new high temperature insulation materials

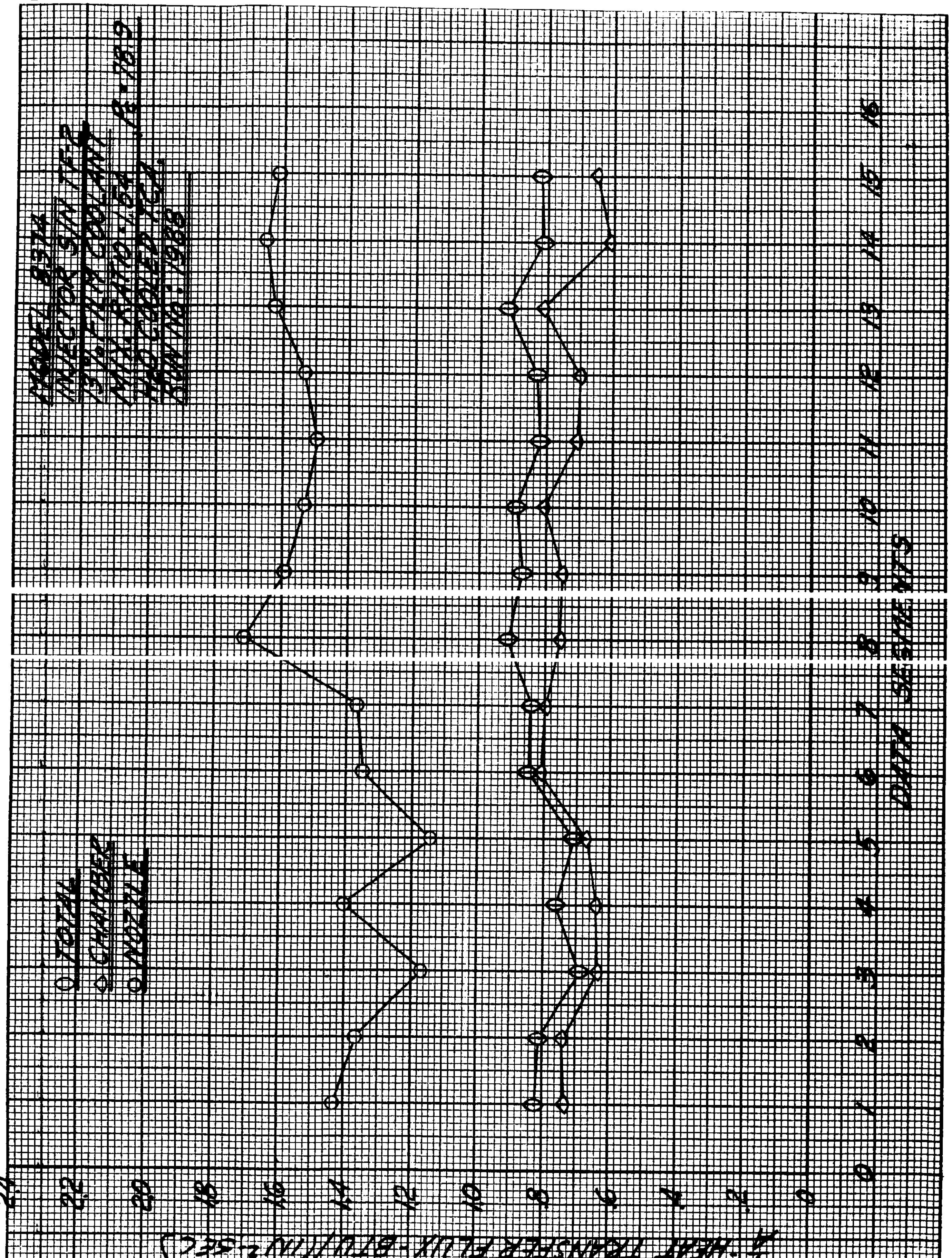
(6) Size/weight optimization considering operating at higher chamber pressures, smaller L*, and shorter nozzles (RAO).

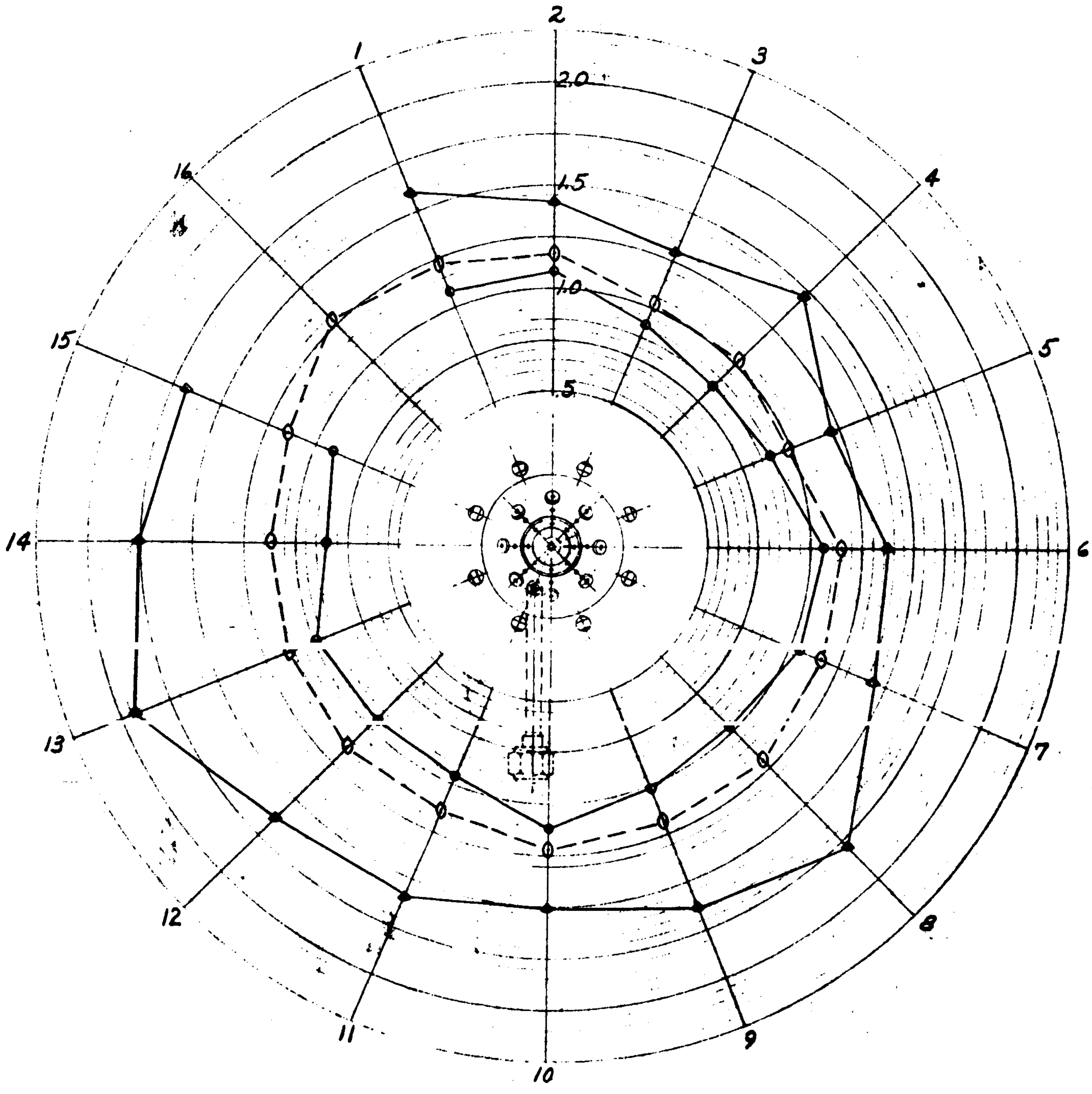
(7) Engine evaluation using Dyna Quartz insulation insteady of composite.

(8) Definition of the engines endurance capabilities as a radiation cooled device.

It is further suggested that the engine concept be evaluated at other thrust levels that present studies indicate will be optimal for future applications.

APPENDIX I


MODEL 8374
INJECTOR S/N TF-2
RUN NO. 1988
○ TOTAL
◇ CHAMBER
○ NOZZLE
DATA SEGMENTS
HEAT TRANSFER FLUX - BTU/(IN² - SEC)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
24
22
20
18
16
14
12
10
8
6
4
2
0

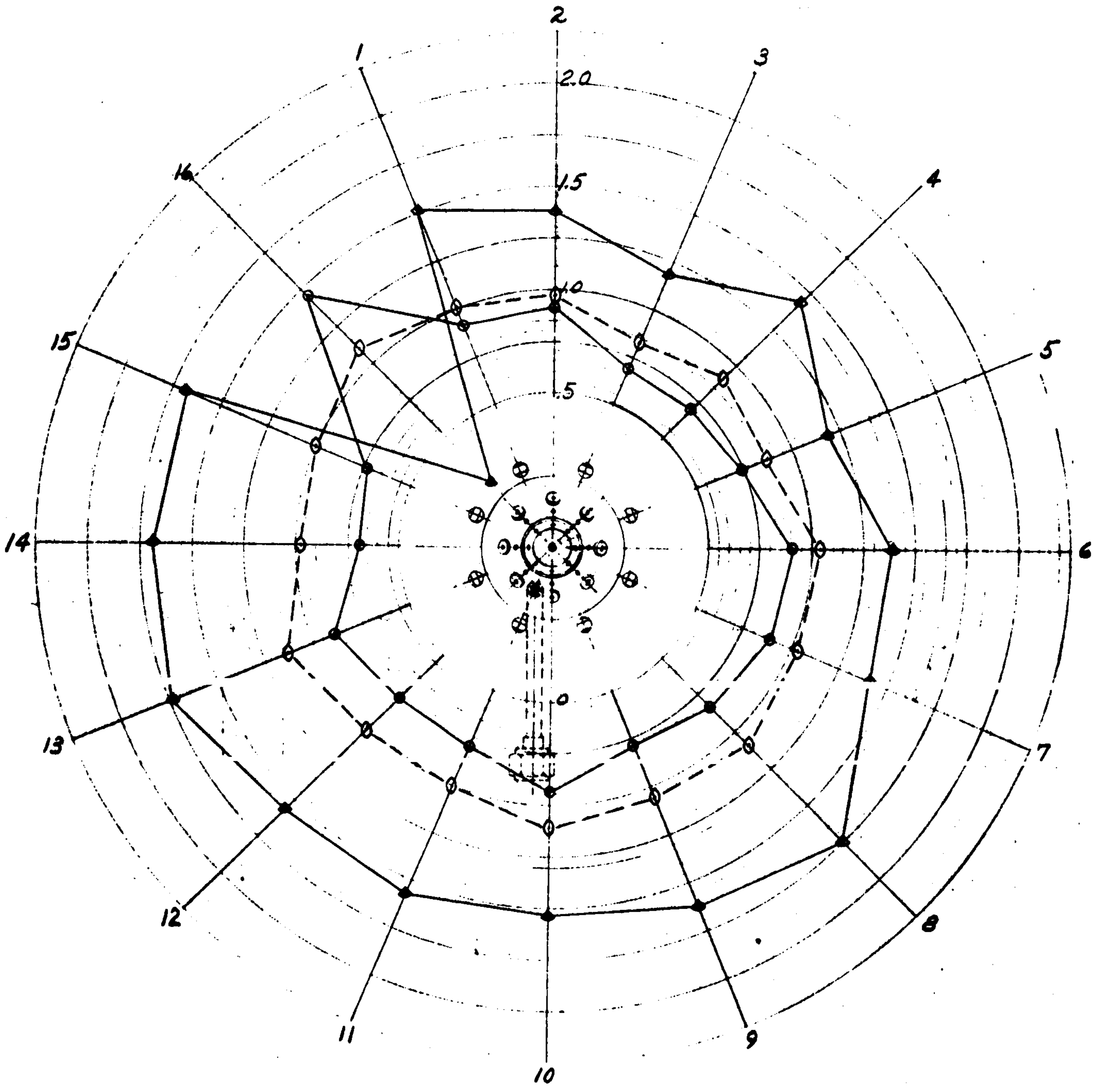


0 Heat Flux (Entire Unit) in BTU/(in.^{2}-sec)

O Chamber Heat Flux in BTU/(in.^{2}-sec)

△ Nozzle Heat Flux in BTU/(in.^{2}-sec)

Model 8374
Injector S/N TF-2
7.3% Film Coolant
H_2O Cooled T.C.A.
Flow Ratio = 1.53, P_c = 79.7
Run No. 1990

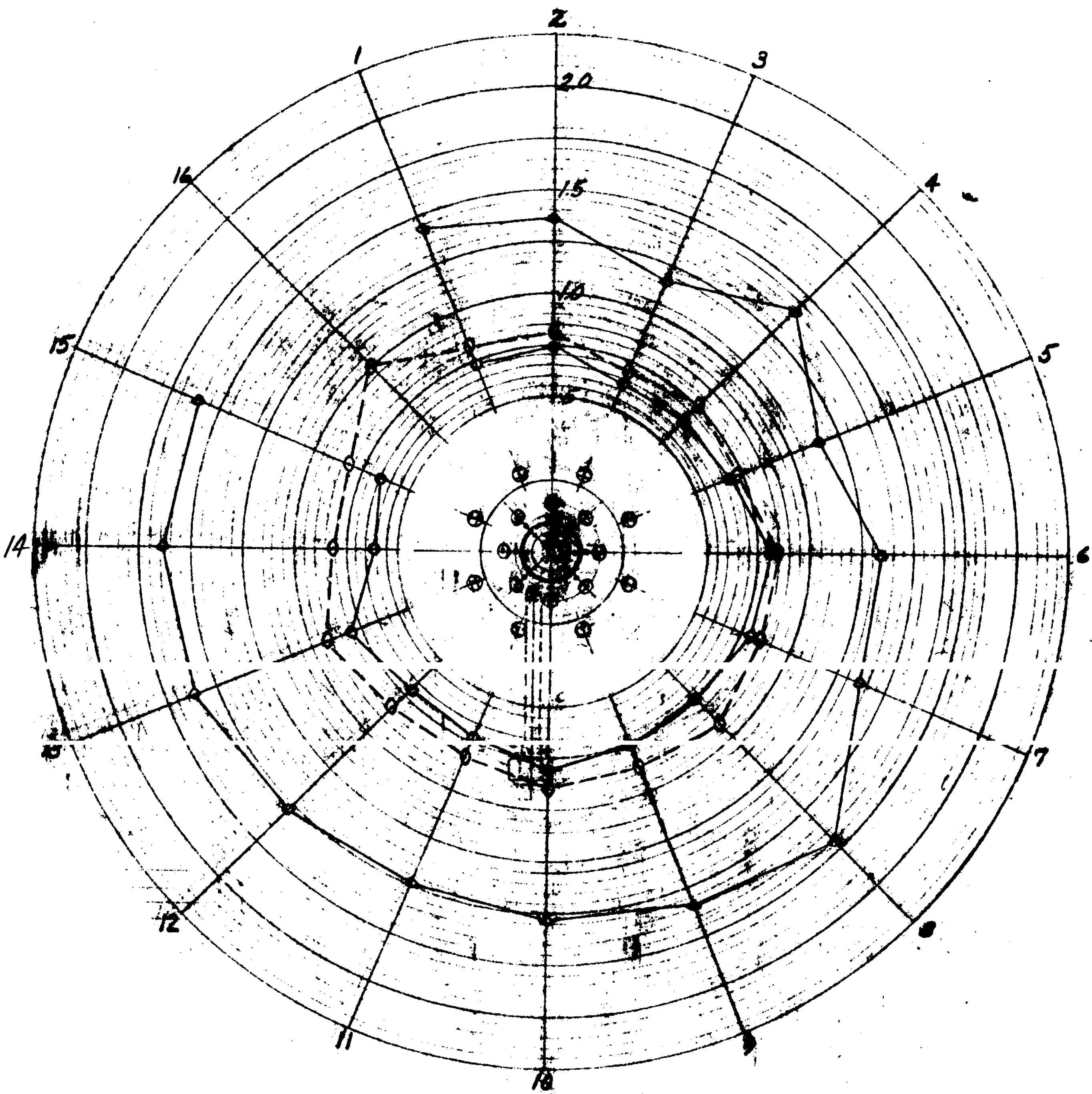


0 Heat Flux (Entire Unit) in BTU/(in.^{2}-sec)

O Chamber Heat Flux in BTU/(in.^{2}-sec)

△ Nozzle Heat Flux in BTU/(in.^{2}-sec)

Model 8374
Injector S/N TF-2
10% Film Coolant
H_2O Cooled T.C.A.
Flow Ratio = 1.53, P_c = 79.2
Run No. 1989

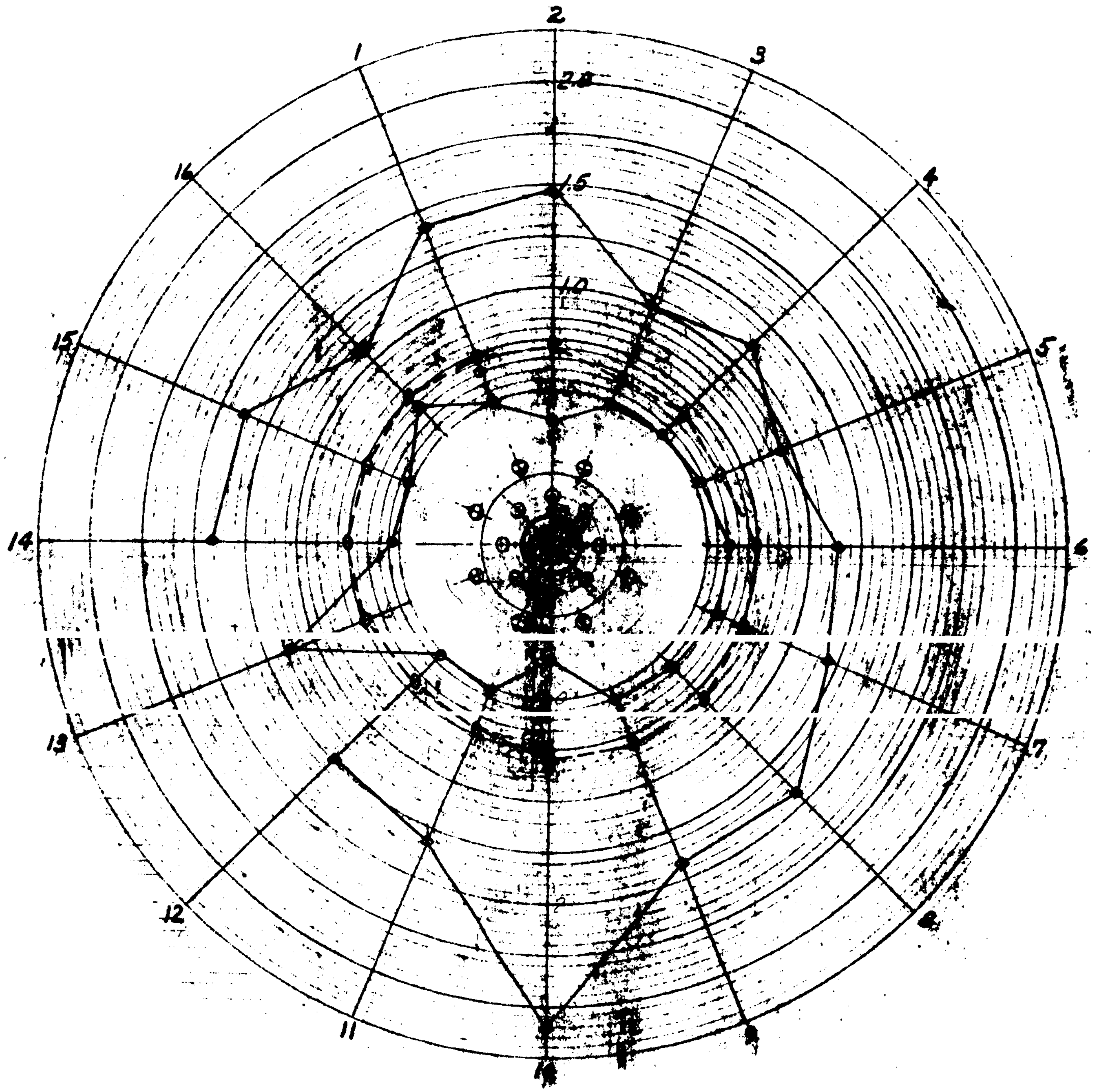


Heat Flux (Entire Unit) in BTU/(in.^{2}-sec)

Chamber Heat Flux in BTU/(in.^{2}-sec)

Nozzle Heat Flux in BTU/(in.^{2}-sec)

Model 8374
Injector S/N TF-2
13% Film Coolant
H_2O Cooled T.C.A.
Flow Ratio = 1.54, P_c = 78.9
Run No. 1988



0 Heat Flux (Entire Unit) in BTU/(in.^{2}-sec)

O Chamber Heat Flux in BTU/(in.^{2}-sec)

△ Nozzle Heat Flux in BTU/(in.^{2}-sec)

Model 8374
Injector S/N TF-2
22.2% Film Coolant
H_2O Cooled T.C.A.
Flow Ratio = 1.48, P_c = 75.2
Run No. 1991

PR

BAROMETRIC PRESS	14.30	PSIA
AMB. AIR TEMP.	37.	DEG.FAHR.
TIME OF RUN	2011.	HRS.
LENGTH OF RUN	30.50	SEC.
FUEL SP.GR.60/60	.875	
OXID.SP.GR.60/60	1.456	

AV

ITEM NO.	PARAMETER DESCRIPTION	
1.	THRUST CHAMBER FUEL FLOW	AVG.
2.	THRUST CHAMBER OXID FLOW	AVG.
3.	THRUST CHAMBER TOTAL FLOW	
4.	THRUST CHAMBER FLOW RATIO	
5.	FUEL FEED TEMPERATURE	
6.	FUEL SPECIFIC GRAVITY AT FFT	
7.	OXID FEED TEMPERATURE	
8.	OXID SPECIFIC GRAVITY AT OLT	
9.	THRUST CHAMBER PRESSURE	AVG.
10.	THRUST CHAMBER CHARACTERISTIC VELOCITY	
11.	FUEL VENTURI INLET PRESSURE	AVG.
12.	FUEL FEED PRESSURE	
13.	OXID VENTURI INLET PRESSURE	AVG.
14.	OXID FEED PRESSURE	
15.	WATER IN TEMPERATURE	AVG.
16.	THRUST CHAMBER SKIN TEMPERATURE	
17.	VALVE PLATE TEMPERATURE	
18.	NOZZLE SKIN TEMPERATURE	
19.	INJECTOR TEMPERATURE	
20.	FUEL COOLANT INLET PRESSURE	
21.	COOLANT WATER FLOW	AVG.
22.	NOZZLE WATER TEMPERATURE NO. 1	
23.	NOZZLE WATER TEMPERATURE NO. 2	
24.	NOZZLE WATER TEMPERATURE NO. 3	
25.	NOZZLE WATER TEMPERATURE NO. 4	
26.	NOZZLE WATER TEMPERATURE NO. 5	
27.	NOZZLE WATER TEMPERATURE NO. 6	
28.	NOZZLE WATER TEMPERATURE NO. 7	
29.	NOZZLE WATER TEMPERATURE NO. 8	
30.	NOZZLE WATER TEMPERATURE NO. 9	
31.	NOZZLE WATER TEMPERATURE NO.10	
32.	NOZZLE WATER TEMPERATURE NO.11	
33.	NOZZLE WATER TEMPERATURE NO.12	
34.	NOZZLE WATER TEMPERATURE NO.13	
35.	NOZZLE WATER TEMPERATURE NO.14	
36.	NOZZLE WATER TEMPERATURE NO.15	
~~37.~~	~~NOZZLE WATER TEMPERATURE~~ NO.16	

ƎELL AEROSYSTEMS COMPANY

REPORT (SAMPLE)

.270 IN.SQD.		MODEL NO.	8374
9500 IN.SQD.		TEST DATE	11204
9015 IN.SQD.		TEST CELL	20200
.000 IN.SQD.		TEST NO.	2019
0		T.C. S/N	1
0		INJ. S/N	TS-4

PUTED DATA

		SECONDS			
DIMENSION	STATIC	26.0	27.0	28.0	29.0
LBS/SEC		.1332	.1332	.1332	.1333
LBS/SEC		.2077	.2074	.2077	.2077
LBS/SEC		.3409	.3406	.3409	.3410
		1.5587	1.5578	1.5593	1.5584
DEG.FAHR	59.2	63.5	63.6	63.6	63.7
		.8733	.8732	.8732	.8732
DEG.FAHR	56.7	59.8	59.9	59.9	60.0
		1.4562	1.4562	1.4561	1.4560
PSIA		82.8	82.7	82.7	82.7
FT/SEC		5390.0	5391.0	5389.2	5385.4
PSIA	547.7	536.3	536.2	536.3	536.4
PSIA		166.3	165.6	165.8	165.6
PSIA	401.4	389.8	389.8	389.8	389.8
PSIA		161.4	161.4	161.4	161.2
DEG.FAHR	82.7	83.0	83.0	83.1	83.1
DEG.FAHR	100.4	178.0	178.0	178.2	178.4
DEG.FAHR	149.7	149.7	149.7	149.7	149.7
DEG.FAHR	84.5	123.6	123.6	123.5	123.6
DEG.FAHR	590.8	590.8	590.8	590.8	590.8
PSIA					
LBS/SEC		.4184	.4163	.4166	.4158
DEG.FAHR	83.2	111.4	111.5	111.7	111.4
DEG.FAHR	83.1	110.9	111.1	111.2	111.4
DEG.FAHR	83.3	119.4	118.6	118.7	119.2
DEG.FAHR	76.9	105.1	106.8	108.7	109.2
DEG.FAHR	83.1	113.4	114.0	114.2	113.8
DEG.FAHR	83.1	112.4	112.4	112.7	112.0
DEG.FAHR	82.7	109.8	110.0	110.1	109.9
DEG.FAHR	83.0	110.1	110.4	110.2	110.4
DEG.FAHR	82.9	108.4	108.7	108.6	108.6
DEG.FAHR	82.9	108.1	108.0	107.9	107.9
DEG.FAHR	82.8	107.2	107.2	107.2	107.1
DEG.FAHR	83.0	108.7	109.3	108.9	109.1
DEG.FAHR	56.9	57.0	57.0	57.0	57.0
DEG.FAHR	82.8	104.8	104.9	105.0	105.0
DEG.FAHR	83.0	109.2	109.3	109.3	109.1
DEG.FAHR	83.1	105.9	105.7	105.9	105.9

-L AEROSYSTEMS COMPANY

ORT (SAMPLE)

IN.SQD.		MODEL NO.	8374
IN.SQD.		TEST DATE	11204
IN.SQD.		TEST CELL	20200
IN.SQD.		TEST NO.	2019
		T.C. S/N	1
		INJ. S/N	TS-4

DATA

		SECONDS			
ENSION	STATIC	26.0	27.0	28.0	29.0
G.FAHR		27.9	27.9	28.1	27.8
G.FAHR		27.4	27.6	27.7	27.9
G.FAHR		35.8	35.0	35.1	35.5
G.FAHR		27.9	29.6	31.4	31.9
G.FAHR		29.9	30.5	30.7	30.3
G.FAHR		28.9	28.9	29.2	28.5
G.FAHR		26.7	26.9	27.0	26.8
G.FAHR		26.8	27.0	26.8	27.0
G.FAHR		25.2	25.4	25.3	25.3
G.FAHR		24.8	24.8	24.6	24.7
G.FAHR		24.0	24.0	24.0	23.9
G.FAHR		25.4	25.9	25.5	25.7
G.FAHR		-.1	-.2	-.2	-.2
G.FAHR		21.6	21.7	21.7	21.7
G.FAHR		25.8	25.9	25.8	25.7
G.FAHR		22.5	22.2	22.4	22.4
.BS/SEC		.0264	.0263	.0263	.0263
.BS/SEC		.0236	.0235	.0235	.0235
.BS/SEC		.0201	.0200	.0200	.0200
.BS/SEC		.0205	.0204	.0204	.0203
.BS/SEC		.0210	.0209	.0209	.0209
.BS/SEC		.0234	.0233	.0233	.0233
.BS/SEC		.0256	.0255	.0255	.0255
.BS/SEC		.0284	.0283	.0283	.0283
.BS/SEC		.0296	.0294	.0295	.0294
.BS/SEC		.0303	.0302	.0302	.0301
.BS/SEC		.0284	.0283	.0283	.0283
.BS/SEC		.0277	.0276	.0276	.0276
.BS/SEC		.0297	.0296	.0296	.0296
.BS/SEC		.0279	.0278	.0278	.0277
.BS/SEC		.0272	.0270	.0270	.0270
.BS/SEC		.0283	.0281	.0282	.0281

REPORT (SAMPLE)

70 IN.SQD.		MODEL NO.	8374
00 IN.SQD.		TEST DATE	11204
15 IN.SQD.		TEST CELL	20200
00 IN.SQD.		TEST NO.	2019
0		T.C. S/N	1
0		INJ. S/N	TS-4

TED DATA

		SECONDS			
DIMENSION	STATIC	26.0	27.0	28.0	29.0
BTU/SEC		.7394	.7380	.7424	.7335
BTU/SEC		.6511	.6520	.6535	.6570
BTU/SEC		.7217	.7012	.7038	.7115
BTU/SEC		.5726	.6040	.6416	.6506
BTU/SEC		.6311	.6402	.6446	.6350
BTU/SEC		.6798	.6761	.6843	.6668
BTU/SEC		.6885	.6888	.6920	.6848
BTU/SEC		.7650	.7676	.7629	.7674
BTU/SEC		.7475	.7496	.7488	.7453
BTU/SEC		.7564	.7500	.7459	.7466
BTU/SEC		.6864	.6829	.6835	.6782
BTU/SEC		.7066	.7188	.7084	.7111
BTU/SEC		-.0070	-.0074	-.0079	-.0079
BTU/SEC		.6060	.6042	.6068	.6056
BTU/SEC		.7041	.7021	.7017	.6968
BTU/SEC		.6381	.6280	.6326	.6333
C/IN.SQD		1.4614	1.4586	1.4673	1.4499
C/IN.SQD		1.2869	1.2887	1.2917	1.2985
C/IN.SQD		1.4265	1.3859	1.3912	1.4063
C/IN.SQD		1.1318	1.1938	1.2681	1.2858
C/IN.SQD		1.2474	1.2654	1.2741	1.2550
C/IN.SQD		1.3437	1.3364	1.3525	1.3179
C/IN.SQD		1.3608	1.3614	1.3678	1.3535
C/IN.SQD		1.5120	1.5171	1.5079	1.5167
C/IN.SQD		1.4775	1.4816	1.4801	1.4731
C/IN.SQD		1.4950	1.4825	1.4743	1.4756
C/IN.SQD		1.3567	1.3497	1.3510	1.3405
C/IN.SQD		1.3967	1.4207	1.4001	1.4056
C/IN.SQD		-.0139	-.0148	-.0157	-.0157
C/IN.SQD		1.1978	1.1943	1.1994	1.1970
C/IN.SQD		1.3917	1.3878	1.3869	1.3773
C/IN.SQD		1.2612	1.2413	1.2504	1.2518

ELL AEROSYSTEMS COMPANY

EPORT (SAMPLE)

0 IN.SQD.	MODEL NO.	8374
0 IN.SQD.	TEST DATE	11204
5 IN.SQD.	TEST CELL	20200
0 IN.SQD.	TEST NO.	2019
0	T.C. S/N	1
0	INJ. S/N	TS-4

ED DATA

			SECONDS		
IMENSION	STATIC	26.0	27.0	28.0	29.0
DEG.FAHR	86.2	176.6	176.9	177.1	177.5
DEG.FAHR	84.6	178.8	179.4	179.1	179.2
DEG.FAHR	84.8	183.7	183.9	184.0	184.2
DEG.FAHR	87.0	190.6	190.3	190.6	190.8
DEG.FAHR	87.1	192.6	192.7	193.0	193.5
DEG.FAHR	85.4	186.7	186.7	186.8	187.2
DEG.FAHR	84.0	184.2	184.6	184.8	184.3
DEG.FAHR	84.7	170.4	170.4	170.5	170.3
DEG.FAHR	83.8	168.8	168.7	168.6	168.8
[redacted]	[redacted]	[redacted]	170.0	169.9	169.9
DEG.FAHR	86.1	172.2	172.5	172.4	172.6
DEG.FAHR	85.7	170.9	168.1	168.0	168.1
DEG.FAHR	84.4	168.3	168.6	168.8	168.7
DEG.FAHR	84.0	170.0	170.0	170.0	169.6
DEG.FAHR	84.0	173.4	173.9	173.8	173.1
DEG.FAHR	84.5	172.8	172.9	173.0	172.6
DEG.FAHR		62.2	62.3	62.4	63.1
DEG.FAHR		66.4	66.7	66.4	66.3
DEG.FAHR		62.8	63.8	63.8	63.5
DEG.FAHR		75.4	73.4	71.9	71.6
DEG.FAHR		75.2	74.7	74.8	75.7
DEG.FAHR		72.1	72.1	71.8	73.0
DEG.FAHR		73.2	73.4	73.5	73.2
DEG.FAHR		58.6	58.3	58.6	58.2
DEG.FAHR		59.5	59.2	59.1	59.4
DEG.FAHR		60.5	60.6	60.7	60.6
DEG.FAHR		61.7	62.0	61.9	62.2
DEG.FAHR		59.4	56.1	56.3	56.3
DEG.FAHR		83.7	84.1	84.3	84.1
DEG.FAHR		64.0	63.9	63.8	63.4
DEG.FAHR		63.2	63.7	63.6	63.1
DEG.FAHR		65.5	65.8	65.8	65.3

PREI

BAROMETRIC PRESS	14.30	PSIA
AMB. AIR TEMP.	37.	DEG.FAHR.
TIME OF RUN	2011.	HRS.
LENGTH OF RUN	30.50	SEC.
FUEL SP.GR.60/60	.875	
OXID.SP.GR.60/60	1.456	

AVEI

ITEM NO.	PARAMETER DESCRIPTION
134.	WATER FLOW THRU SEGMENT NO. 1
135.	WATER FLOW THRU SEGMENT NO. 2
136.	WATER FLOW THRU SEGMENT NO. 3
137.	WATER FLOW THRU SEGMENT NO. 4
138.	WATER FLOW THRU SEGMENT NO. 5
139.	WATER FLOW THRU SEGMENT NO. 6
140.	WATER FLOW THRU SEGMENT NO. 7
141.	WATER FLOW THRU SEGMENT NO. 8
142.	WATER FLOW THRU SEGMENT NO. 9
143.	WATER FLOW THRU SEGMENT NO.10
144.	WATER FLOW THRU SEGMENT NO.11
145.	WATER FLOW THRU SEGMENT NO.12
146.	WATER FLOW THRU SEGMENT NO.13
147.	WATER FLOW THRU SEGMENT NO.14
148.	WATER FLOW THRU SEGMENT NO.15
149.	WATER FLOW THRU SEGMENT NO.16
150.	CHAMBER HEAT TRANSFER RATE NO. 1
151.	CHAMBER HEAT TRANSFER RATE NO. 2
152.	CHAMBER HEAT TRANSFER RATE NO. 3
153.	CHAMBER HEAT TRANSFER RATE NO. 4
154.	CHAMBER HEAT TRANSFER RATE NO. 5
155.	CHAMBER HEAT TRANSFER RATE NO. 6
156.	CHAMBER HEAT TRANSFER RATE NO. 7
157.	CHAMBER HEAT TRANSFER RATE NO. 8
158.	CHAMBER HEAT TRANSFER RATE NO. 9
159.	CHAMBER HEAT TRANSFER RATE NO.10
160.	CHAMBER HEAT TRANSFER RATE NO.11
161.	CHAMBER HEAT TRANSFER RATE NO.12
162.	CHAMBER HEAT TRANSFER RATE NO.13
163.	CHAMBER HEAT TRANSFER RATE NO.14
164.	CHAMBER HEAT TRANSFER RATE NO.15
165.	CHAMBER HEAT TRANSFER RATE NO.16

) BELL AEROSYSTEMS COMPANY

Γ REPORT (SAMPLE)

).270 IN.SQD.	MODEL NO.	8374
)9500 IN.SQD.	TEST DATE	11204
;9015 IN.SQD.	TEST CELL	20200
.000 IN.SQD.	TEST NO.	2019
0	T.C. S/N	1
0	INJ. S/N	TS-4

IPUTED DATA

		SECONDS			
DIMENSION	STATIC	26.0	27.0	28.0	29.0
LBS/SEC		.0264	.0263	.0263	.0263
LBS/SEC		.0236	.0235	.0235	.0235
LBS/SEC		.0201	.0200	.0200	.0200
LBS/SEC		.0205	.0204	.0204	.0203
LBS/SEC		.0210	.0209	.0209	.0209
LBS/SEC		.0234	.0233	.0233	.0233
LBS/SEC		.0256	.0255	.0255	.0255
LBS/SEC		.0284	.0283	.0283	.0283
LBS/SEC		.0296	.0294	.0295	.0294
LBS/SEC		.0303	.0302	.0302	.0301
LBS/SEC		.0284	.0283	.0283	.0283
LBS/SEC		.0277	.0276	.0276	.0276
LBS/SEC		.0297	.0296	.0296	.0296
LBS/SEC		.0279	.0278	.0278	.0277
LBS/SEC		.0272	.0270	.0270	.0270
LBS/SEC		.0283	.0281	.0282	.0281
BTU/SEC		1.6526	1.6487	1.6510	1.6676
BTU/SEC		1.5775	1.5777	1.5716	1.5665
BTU/SEC		1.2668	1.2804	1.2818	1.2731
BTU/SEC		1.5505	1.5017	1.4724	1.4628
BTU/SEC		1.5878	1.5692	1.5717	1.5880
BTU/SEC		1.6970	1.6886	1.6836	1.7073
BTU/SEC		1.8866	1.8814	1.8865	1.8746
BTU/SEC		1.6742	1.6586	1.6678	1.6538
BTU/SEC		1.7691	1.7506	1.7507	1.7542
BTU/SEC		1.8439	1.8381	1.8414	1.8357
BTU/SEC		1.7653	1.7643	1.7630	1.7676
BTU/SEC		1.6563	1.5557	1.5641	1.5603
BTU/SEC		2.5030	2.5004	2.5092	2.4990
BTU/SEC		1.7941	1.7835	1.7824	1.7681
BTU/SEC		1.7254	1.7293	1.7293	1.7103
BTU/SEC		1.8610	1.8622	1.8625	1.8460

ELL AEROSYSTEMS COMPANY

EPORT (SAMPLE)

0 IN.SQD.		MODEL NO.	8374
0 IN.SQD.		TEST DATE	11204
5 IN.SQD.		TEST CELL	20200
0 IN.SQD.		TEST NO.	2019
0		T.C. S/N	1
0		INJ. S/N	TS-4

ED DATA

			SECONDS		
IMENSION	STATIC	26.0	27.0	28.0	29.0
C/IN.SQD		1.3045	1.3014	1.3032	1.3163
C/IN.SQD		1.2452	1.2454	1.2406	1.2365
C/IN.SQD		.9999	1.0107	1.0118	1.0049
C/IN.SQD		1.2239	1.1854	1.1622	1.1546
C/IN.SQD		1.2533	1.2387	1.2406	1.2535
C/IN.SQD		1.3395	1.3329	1.3289	1.3476
C/IN.SQD		1.4892	1.4851	1.4891	1.4797
C/IN.SQD		1.3215	1.3092	1.3165	1.3054
C/IN.SQD		1.3964	1.3818	1.3819	1.3846
C/IN.SQD		1.4555	1.4509	1.4535	1.4490
C/IN.SQD		1.3934	1.3926	1.3916	1.3953
C/IN.SQD		1.3074	1.2280	1.2347	1.2316
C/IN.SQD		1.9757	1.9737	1.9806	1.9726
C/IN.SQD		1.4161	1.4078	1.4069	1.3956
C/IN.SQD		1.3619	1.3650	1.3650	1.3500
C/IN.SQD		1.4689	1.4699	1.4702	1.4571
BTU/SEC		2.3920	2.3866	2.3934	2.4012
BTU/SEC		2.2286	2.2297	2.2252	2.2235
BTU/SEC		1.9885	1.9816	1.9856	1.9846
BTU/SEC		2.1231	2.1057	2.1140	2.1133
BTU/SEC		2.2189	2.2095	2.2163	2.2230
BTU/SEC		2.3769	2.3648	2.3679	2.3741
BTU/SEC		2.5751	2.5702	2.5785	2.5594
BTU/SEC		2.4392	2.4261	2.4307	2.4212
BTU/SEC		2.5166	2.5001	2.4996	2.4995
BTU/SEC		2.6003	2.5882	2.5873	2.5823
BTU/SEC		2.4517	2.4471	2.4466	2.4458
BTU/SEC		2.3629	2.2745	2.2725	2.2715
BTU/SEC		2.4959	2.4929	2.5012	2.4910
BTU/SEC		2.4001	2.3878	2.3892	2.3737
BTU/SEC		2.4295	2.4314	2.4310	2.4071
BTU/SEC		2.4991	2.4903	2.4951	2.4793

REPORT (SAMPLE)

.270 IN.SQD.		MODEL NO.	8374
9500 IN.SQD.		TEST DATE	11204
9015 IN.SQD.		TEST CELL	20200
.000 IN.SQD.		TEST NO.	2019
0		T.C. S/N	1
0		INJ. S/N	TS-4

PUTED DATA

DIMENSION	STATIC	26.0	27.0	28.0	29.0
		SECONDS			
/SEC/IN.SQD		1.3493	1.3462	1.3500	1.3544
/SEC/IN.SQD		1.2571	1.2577	1.2552	1.2542
/SEC/IN.SQD		1.1217	1.1178	1.1200	1.1194
/SEC/IN.SQD		1.1976	1.1878	1.1924	1.1921
/SEC/IN.SQD		1.2516	1.2463	1.2502	1.2539
/SEC/IN.SQD		1.3407	1.3339	1.3357	1.3392
/SEC/IN.SQD		1.4526	1.4498	1.4545	1.4437
/SEC/IN.SQD		1.3759	1.3685	1.3711	1.3657
/SEC/IN.SQD		1.4196	1.4103	1.4099	1.4099
/SEC/IN.SQD		1.4668	1.4599	1.4594	1.4566
/SEC/IN.SQD		1.3830	1.3804	1.3801	1.3796
/SEC/IN.SQD		1.3329	1.2830	1.2819	1.2813
/SEC/IN.SQD		1.4079	1.4062	1.4109	1.4051
/SEC/IN.SQD		1.3538	1.3469	1.3477	1.3389
/SEC/IN.SQD		1.3704	1.3715	1.3713	1.3578
/SEC/IN.SQD		1.4097	1.4047	1.4074	1.3985

APPENDIX II

COMPUTER PROGRAMS

PROGRAM NUMBER - 3262

TITLE ---------- THREE-DIMENSIONAL TRANSIENT HEAT TRANSFER PROGRAM WITH ARBITRARY INITIAL AND BOUNDARY CONDITIONS

DESCRIPTION ----- Program 3262 is a generalized heat transfer program for computing the transient temperature distribution within a simple or complex network made up of as many as 150 nodes. This program is an advanced version of an earlier program, number 1740, that had somewhat less sophistication but has been in use for over five years. The new program is written in FORTRAN IV. Any or all nodes may be involved in a transfer of heat by conduction and/or radiation interchange with any or all other nodes in the same network. Radiation to space and incident solar and/or nocturnal radiation may be included. Temperature dependent material thermal properties may be functionally inputted. Initial and boundary conditions are imposed by relating nodes in the network to control nodes by conduction, convection, and/or radiation. For the control nodes, the known temperatures, and for convection the heat transfer film coefficients may be held constant or may vary with time. The film coefficients may be dependent upon the resulting temperatures of the network nodes. Known levels of heat flux versus time may also be applied to the network nodes. An additional option allows the setting of prescribed temperature limits versus time for selected network nodes. In this option the temperatures of the governed nodal points are computed and compared with the limits. The temperatures then assigned to the nodes will be less than, greater than, or equal to the limits, depending upon the instructions. The program output includes the network node temperatures at selected time intervals and, if desired, the values of heat flux by the various modes of heat transfer to or from selected nodal points in the network and to or from selected control nodes.

PROGRAM NUMBER - 1757

TITLE - - - - - - - - - - THREE-DIMENSIONAL STEADY STATE HEAT TRANSFER PROGRAM WITH ARBITRARY BOUNDARY CONDITIONS

DESCRIPTION - - - - - Program 1757 is a generalized heat transfer program for computing the steady state temperature distribution within a simple or complex network made up of as many as 80 nodal points. Any or all nodes may be involved in a transfer of heat by conduction, and/or radiation interchange with any or all other nodes in the same network. Conduction between nodes includes the effect of temperature dependent values of thermal conductivity. Boundary conditions are imposed by relating nodes in the network to control nodes of known temperatures by any or all modes of heat transfer - - conduction, convection, and radiation. Convection film coefficients between nodes in the network and control nodes may be dependent upon the resulting temperatures of the network nodes concerned. Known levels of heat flux also may be applied to the network. In addition to the steady state temperature distribution, the program output can include the values of heat flow by the various modes of heat transfer to or from selected nodal points in the network and to or from selected control nodes.

APPENDIX III

INJECTOR CONFIGURATION DETAILS

Injector S/N		Injector Orifices Outer Fuel	Inner Fuel	Outer Ox.	Inner Ox.
T-1	Dia. (in.)	0.0197	0.0197	0.0310	
	Angle (°)	30	30	-	
TF-2	Dia. (in.)	0.0210	0.0210	0.0370	
	Angle (°)	30	30	-	
TU-3	Dia. (in.)	0.0260	0.0210	0.0330	
	Angle (°)	30	50	-	
TS-4	Dia. (in.)	0.0225	0.0200	0.0225	0.0250
	Angle (°)	30	30	-	-
TF-5	Dia. (in.)	0.0225	0.0160	0.0210	0.0250
	Angle (°)	18	30	20	10
TU-6	Dia. (in.)	0.0236	0.0196	0.0350	
	Angle (°)	30	50	-	

CREDITS

The effort of the following NASA and JPL personnel and Bell Rockets Propulsion personnel culminated in the successful completion of the Model 8374 Experimental Auxiliary Rocket Engine Program (NAS7-305).

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